

# CALiPER

## Exploratory Study

Retail Replacement Lamps – 2011

April 2012

**Prepared for:**

**Solid-State Lighting Program**

Building Technologies Program  
Office of Energy Efficiency and  
Renewable Energy  
U.S. Department of Energy

**Prepared by:**

Pacific Northwest National  
Laboratory

## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY  
*operated by*  
BATTELLE  
*for the*  
UNITED STATES DEPARTMENT OF ENERGY  
*under Contract DE-AC05-76RL01830*

Printed in the United States of America

Available to DOE and DOE contractors from the  
Office of Scientific and Technical Information,  
P.O. Box 62, Oak Ridge, TN 37831-0062;  
ph: (865) 576-8401  
fax: (865) 576-5728  
email: [reports@adonis.osti.gov](mailto:reports@adonis.osti.gov)

Available to the public from the National Technical Information Service  
5301 Shawnee Rd., Alexandria, VA 22312  
ph: (800) 553-NTIS (6847)  
email: [orders@ntis.gov](mailto:orders@ntis.gov) <<http://www.ntis.gov/about/form.aspx>>  
Online ordering: <http://www.ntis.gov>



This document was printed on recycled paper.

(8/2010)

# 1 Preface

---

The U.S. Department of Energy (DOE) CALiPER program has been purchasing and testing general illumination solid-state lighting (SSL) products since 2006. CALiPER relies on standardized photometric testing (following the Illuminating Engineering Society of North America [IES] approved method LM-79-08<sup>1</sup>) conducted by accredited, independent laboratories.<sup>2</sup> Results from CALiPER testing are available to the public via detailed reports for each product or through summary reports, which assemble data from several product tests and provide comparative analyses.<sup>3</sup>

This is a special report on LED replacement lamps being sold at retail stores, which follows the first report on this topic published in April 2011. It is not possible for CALiPER to test every SSL product on the market, especially given the rapidly growing variety of products and changing performance characteristics. Products selected for testing in this special program were chosen with the intent of capturing the current state of the retail LED lamp market—a cross section ranging from expected low to high performing products with the bulk characterizing the average of the range. The selection does not represent a statistical sample of all available products or all retailers selling LED lamps. To provide further context, the CALiPER test results are compared to data from LED Lighting Facts<sup>4</sup> and ENERGY STAR<sup>®</sup> performance criteria.<sup>5</sup> CALiPER also tries to purchase conventional (i.e., non-SSL) products for comparison, but because the primary focus is SSL, the program can only test a limited number.

It is important for buyers and specifiers to reduce risk by learning how to compare products and by considering every potential SSL purchase carefully. CALiPER test results are a valuable resource, providing photometric data for anonymously purchased products as well as objective analysis and comparative insights. However, LM-79-08 testing alone is not enough to fully characterize a product—quality, reliability, controllability, physical attributes, warranty, compatibility, and many other facets should also be considered carefully.

For more information on the DOE SSL program, please visit <http://www.ssl.energy.gov>.

---

<sup>1</sup> IES LM-79-08, *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*, covers LED-based SSL products with control electronics and heat sinks incorporated. For more information, visit <http://www.iesna.org/>.

<sup>2</sup> CALiPER uses independent testing laboratories with LM-79-08 accreditation that includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP).

<sup>3</sup> CALiPER reports are available at <http://www.ssl.energy.gov/reports.html>. Detailed test reports for individual products can also be obtained from <http://www.ssl.energy.gov/search.html>.

<sup>4</sup> LED Lighting Facts is a program of the U.S. Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. The DOE LED Lighting Facts program is separate from the Lighting Facts label required by the Federal Trade Commission (FTC). For more information, see <http://www.lightingfacts.com>.

<sup>5</sup> ENERGY STAR is a federal program promoting energy efficiency. For more information, visit <http://www.energystar.gov>.

## 2 Report Summary

---

In 2010, CALiPER conducted a study on LED replacement lamps found in retail stores. The results were less than satisfactory, and many products were classified as being unlikely to meet consumer expectations. In November 2011, CALiPER purchased a new sample of products for a follow-up study, with the intent of characterizing the progress of this essential market segment. For the 2011 study, 38 LED replacement lamps were tested, including 11 A19 lamps, 5 G25 lamps, 9 120 V MR16/PAR16 lamps, 5 PAR20/R20 lamps, and 8 PAR30/R30 lamps. This report provides the test results and comparisons to earlier CALiPER testing, as well as other relevant performance criteria. Performance evaluations are presented grouped by manufacturer, product type, and retailer.

The results of the second retail replacement lamp study indicate substantial improvement across many performance characteristics, as well as better performance at a given price. Besides notable increases in lumen output and efficacy, retailers stocked more products that performed as indicated by manufacturer's claims, more products included the ENERGY STAR and/or LED Lighting Facts labels, equivalency claims were more accurate, and color quality improved. Specifically, in comparison to the first retail replacement lamp study:

- There continued to be a range in performance, but fewer products were considered unacceptable in terms of lumen output, efficacy, and color quality.
- A much higher percentage of products had performance similar to the incandescent and compact fluorescent (CFL) lamps they were intended to replace.
- Many more products were listed by LED Lighting Facts or were ENERGY STAR qualified; this is likely to foster more effective consumer evaluations.
- With a much higher percentage of products measured within tolerance of listed performance values, there were fewer obvious disparities between different manufacturers and different retailers.

The best outcome for the future would be to have high-quality products displace lower-quality products at low price points. Because many LED replacement lamps have reached appropriate levels of lumen output compared to conventional lamps, it is reasonable to expect that future reductions in price per lumen will result from a reduction in price, rather than an increase in lumen output. Currently, as manufacturers introduce products with higher lumen output, products with lower lumen output are often discontinued. This creates a void for consumers seeking to replace lower wattage conventional lamps, and should be remedied in the future. Creating product families will increase the probability of a consumer finding and purchasing an LED lamp that will meet expectations.

### 3 Background

---

The retail marketplace is the primary avenue through which consumers—especially homeowners, small contractors, and small businesses—are introduced to SSL technology. As with other new technologies, a user's first experience with an unfamiliar product has a remarkable ability to shape his or her perception. Thus, avoiding a repetition of the negative consumer experiences that occurred when CFL lamps were introduced is paramount to successful market adoption of LED lamps.<sup>6</sup> In order to facilitate the transition, consumer education and access to quality products are essential.

Having high-performance products on the shelves at retail stores—and having those products meet the claims made by both the manufacturer and retailer—is particularly important for LEDs given their substantial initial-cost premium. Although the cost per lumen dropped by more than 50% between August 2010 and November 2011, LED replacement lamps are still more expensive per lumen than other energy-efficient alternatives, such as CFLs. As LED efficacy surpasses that of CFL in the very near future—the best products already do—LED lamps will become the more logical choice from an energy use standpoint, but equally important is their performance in areas such as lifetime, color quality, and luminous intensity distribution. Other operational characteristics—such as dimmability, startup functionality, flicker, and compatibility with existing hardware—may also play a key role in achieving widespread market adoption. As seen during the emergence of CFLs, consumers care about more than just the quantity of light emitted and the energy used.

#### Program Goals and Summary

By 2010, many SSL stakeholders were concerned that the increasing availability of poorly performing LED lamps in retail stores could result in widespread buyer dissatisfaction with SSL technology. Although CALiPER had tested many high-performance products, the large disparity among retail products—representing only a portion of the overall LED market—was troubling because buyers in the retail market are typically not as discerning as lighting designers and other specifiers. Beginning in July 2010, a special effort was initiated to identify and test LED replacement lamps available to the public through retail stores and websites. In April 2011, DOE published its first report on retail replacement lamps,<sup>7</sup> and made the following observations:

- The disparity between high-performing and low-performing products was striking.
- While there were some high-performing LED replacement lamps available through retail channels, most of the products tested failed to meet basic performance levels of the incandescent, halogen, or CFL lamps they intended to replace.
- To be able to determine whether or not an LED replacement lamp would meet performance expectations, consumers would have to be highly informed about lamp performance characteristics and would have to develop mechanisms to recognize and understand factual information from product labeling.
- There were substantial differences among manufacturers; some made LED replacement lamps that consistently met expectations, but others were very inconsistent.
- There were substantial differences among retailers; some appeared to screen the LED lamps they carried, with most of the products performing well and having suitable labeling, whereas others did not.

---

<sup>6</sup> See US Department of Energy report, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*, available at [http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl\\_lessons\\_learned\\_web.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf).

<sup>7</sup> For more information, see *Special Summary Report: Retail Replacement Lamp Testing*, available at <http://www1.eere.energy.gov/buildings/ssl/reports.html>.

With these results as a foundation, a second retail replacement lamp study commenced with product purchasing in November 2011. The goal was to capture a new snapshot of the market and evaluate performance changes with respect to retailers, manufacturers, and product types. The overall scope was similar to the previous retail replacement lamp study. In selecting products, the intent was to capture a representative sample of the different general illumination LED products currently available—including omnidirectional, directional, and decorative lamps—from a variety of popular retail outlets. In all, 38 products were tested, including 11 A19 lamps, 5 G25 lamps, 9 120 V MR16/PAR16 lamps, 5 PAR20/R20 lamps, and 8 PAR30/R30 lamps. None of the products selected had been previously tested by CALiPER. Six of the eight retailers examined in the first retail replacement lamp study were examined again, and three new retailers were added.

## Product Selection and Procurement

Product selection included a detailed analysis of currently available products. An initial list of products was established by searching the websites of numerous retailers. The list was then verified and modified after visiting physical stores, if possible. The five specific lamp types were chosen based on the goal of achieving a diversity of manufacturers and retailers, with at least five products per lamp type, and with consideration for what was tested in the 2010 study. In many cases, there was substantial overlap in the products sold at different retailers, which limited the overall number of retailers included. To provide a more representative analysis of each retailer, the tabulations in this report include not only the products purchased from a given retailer, but any of the tested products that were sold by the retailer.

Four of the five product types tested for this study were carryovers from the first retail replacement study (A19, 120 V MR16, PAR20, and PAR30). B10 and C7 lamps were not tested again, but G25 lamps were added to represent decorative lamps. In the second study, only 120 V MR16 lamps were chosen, whereas no limitations were implemented for the first study. In this report, the most common designations were used to establish the lamp type categories, but the notation for specific products sometimes varied. For example, lamps labeled as MR16, PAR16, R16, or simply GU10<sup>8</sup> are all part of the MR16 category. Similarly, although the labels PAR20 and PAR30 are used in this report, lamps using the R designation were also included.<sup>9</sup> Once the final selection list was established, six samples of each product were purchased in November 2011. Acquisition was accomplished in-store and through retailer websites. In-store purchases were made in the Portland, OR, Richland, WA, or Boston, MA areas. The following notes describe some of the unique situations that arose during procurement:

- One product (RT61) was purchased from two different retailers due to limited stock; there were negligible differences in the test results. Because products were attributed to a retailer based on availability rather than store of purchase, this did not alter the analysis.
- One product (RT64) was listed as having different performance attributes by different retailers. Further, the product had two different labels with different performance claims on the same shelf at one store.
- One product (RT67) had manufacturer, retailer, and packaging claims that were different from the markings on the lamp itself; the CALiPER test results matched the lamp markings.
- Several products listed more than one performance claim for the same metric on the retailer's website.

---

<sup>8</sup> Although GU10 indicates a base type, not a lamp shape, some products in this category (RT40, RT63, RT75) used this as the main designation on the product packaging.

<sup>9</sup> One difficulty in making appropriate comparisons between LED products and conventional PAR lamps is that directional LED lamps do not use a parabolic aluminized reflector. Therefore, they are often interchangeably classified as either a PAR or R lamps despite the considerable difference between conventional lamps of those designations.

## 4 Results

### CALiPER Testing of LED Replacement Lamps

#### Current Results: 2011 Retail Replacement Lamp Study

Three samples of each product were sent to independent testing laboratories for evaluation according to IES LM-79-08 procedures. A fourth sample was tested for product RT65 because the initial data showed significant differences. The results reported in this document are the mean of all samples, with the exception of  $D_{uv}$ , for which the maximum value (i.e., furthest from the center point of the allowable range) is reported. For this special report, only integrating-sphere testing was performed—a goniophotometer was not used and therefore luminous intensity distribution data were not collected.

Table 1 summarizes the cost, energy performance, and color characteristics for the 38 lamps tested for the 2011 retail replacement lamp study. The products are divided by shape category, but the specific shapes listed by the manufacturer were sometimes different. For definitions of the metrics used in this report, see Appendix A.

**Table 1. Results from the second retail replacement lamp study (2011).** Performance criteria include initial output, total power input, luminous efficacy, power factor, color rendering index (CRI), special color rendering index  $R_9$ , correlated color temperature (CCT), and  $D_{uv}$ . Labels indicate whether the product is listed by ENERGY STAR (ES) or LED Lighting Facts (LF).

DOE CALiPER Test ID	Shape Category <sup>1</sup>	Cost <sup>2</sup> (\$)	Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)	Power Factor	CRI	$R_9$	CCT (K)	$D_{uv}$ <sup>3</sup>	Labels <sup>4</sup>
RT43	A19	18.99	460	8.4	55	0.74	87	40	2958	-0.0020	LF
RT46	A19	23.33	752	12.8	59	0.97	80	10	2991	-0.0060	LF
RT47	A19	9.97	471	7.7	61	0.77	82	15	3054	-0.0010	
RT49	A19	23.97	827	13.3	62	0.99	86	33	3300	-0.0040	ES LF
RT57	A19	12.98	437	7.6	58	0.68	80	13	3020	-0.0010	
RT61	A19	36.89	472	8.0	59	0.99	82	14	3060	-0.0020	ES LF
RT62	A19	16.88	841	11.9	71	0.87	83	22	2730	-0.0010	LF
RT64	A19	11.54	84	1.6	54	0.34	73	-5	3173	-0.0070	
RT72	A19	8.99	313	6.4	49	0.70	76	-10	4863	0.0049	LF
RT74	A19	42.00	414	7.8	53	0.96	86	48	3017	0.0012	
RT77	A19	29.99	585	9.9	59	0.88	80	11	3030	0.0004	ES LF
RT50	G25	24.97	441	8.0	55	0.96	86	49	3026	-0.0009	ES LF
RT54	G25	34.98	371	8.2	45	0.94	86	49	2690	-0.0005	LF
RT58	G25	19.98	442	7.8	56	0.99	82	10	3143	-0.0019	
RT60	G25	14.00	81	2.3	36	0.57	82	23	2921	-0.0029	LF
RT66	G25	31.31	435	9.8	44	0.74	80	12	3136	-0.0011	

(continued on next page)

#### Notes:

1. Shape category is the generic group considered for this report. The actual advertised shape may have been different. For example, some lamps in the PAR30 category were labeled as R30.
2. Cost is the price paid at the retailer where the products were purchased, or the average if products were purchased at more than one store (only applies to RT61).
3. Red values are outside of ANSI-defined limits (ANSI C78.377).
4. Also includes products that are listed by the respective program, but do not have the label on the package.

**Table 1. (continued)**

DOE CALiPER Test ID	Shape Category <sup>1</sup>	Cost <sup>2</sup> (\$)	Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)	Power Factor	CRI	R <sub>9</sub>	CCT (K)	D <sub>uv</sub> <sup>3</sup>	Labels <sup>4</sup>
RT40	MR16	19.31	241	5.6	43	0.63	73	-17	6085	0.0037	
RT51	MR16	19.97	327	5.8	56	0.81	85	30	2983	-0.0030	ES LF
RT53	MR16	22.97	147	3.2	46	0.54	83	28	3044	-0.0041	LF
RT55	MR16	29.98	277	5.0	56	0.76	85	30	2982	-0.0028	LF
RT59	MR16	24.98	281	5.0	57	0.61	82	23	3010	-0.0050	
RT63	MR16	29.88	228	4.3	53	0.54	82	17	3040	-0.0033	ES
RT70	MR16	34.98	165	2.7	61	0.93	86	46	2990	0.0014	
RT71	MR16	26.91	284	5.4	52	0.63	88	37	5492	0.0006	
RT75	MR16	14.99	48	0.8	60	0.29	73	-33	6018	0.0066	
RT41	PAR20	31.17	359	7.4	48	0.69	83	22	3108	-0.0030	LF
RT44	PAR20	19.99	358	6.5	55	0.77	84	32	3050	-0.0050	ES LF
RT52	PAR20	19.97	321	8.0	40	0.97	87	50	3029	0.0010	LF
RT56	PAR20	32.98	547	10.7	51	0.97	94	62	3078	0.0010	LF
RT67	PAR20	10.00	110	2.1	52	0.43	68	-20	3194	0.0100	
RT42	PAR30	25.78	365	8.0	46	0.49	67	-52	3225	0.0061	
RT45	PAR30	32.99	608	10.9	56	0.81	81	21	3073	-0.0032	ES LF
RT48	PAR30	29.99	780	14.2	55	0.72	86	36	3046	-0.0043	ES LF
RT65	PAR30	34.88	820	11.5	72	0.98	80	29	3078	-0.0008	LF
RT68	PAR30	37.97	667	12.3	54	0.82	85	26	3037	-0.0018	ES LF
RT69	PAR30	59.98	485	8.1	60	0.93	86	47	2994	0.0009	ES LF
RT73	PAR30	16.99	346	9.2	38	0.75	85	45	2624	-0.0011	
RT76	PAR30	45.99	368	10.1	37	0.95	82	24	2984	-0.0041	LF

**Notes:**

1. Shape category is the generic group considered for this report. The actual advertised shape may have been different. For example, some lamps in the PAR30 category were labeled as R30.
2. Cost is the price paid at the retailer where the products were purchased, or the average if products were purchased at more than one store (only applies to RT61).
3. Red values are outside of ANSI-defined limits (ANSI C78.377).
4. Also includes products that are listed by the respective program, but do not have the label on the package.

**Past Results: 2010 Retail Replacement Lamp Study and Other Testing**

The CALiPER program previously tested over 60 products that fall within one of the categories considered for this report, including 24 products from the first retail replacement lamp study. A summary of the test results for the first retail replacement lamp study is provided in Appendix B. Detailed reports for all previous tests are available on the CALiPER website.

Other CALiPER replacement lamp data include products purchased between 2007 and January 2011. As a whole, it should not be considered representative of the current performance of these product types. However, some products purchased in these years are still sold. Further, a few of the products are comparable to those products considered in this study, and some may actually exceed performance levels of the current products. Because the LED product market is rapidly developing and performance is highly variable, it can be difficult to know when a product is obsolete.

## CALiPER Tests of Conventional Lamps

In addition to testing LED products, CALiPER tests a limited number of conventional products to serve as performance benchmarks. Six conventional products were tested with this series of retail products, including three 120 V, halogen, GU10-base MR16 lamps; two incandescent G25 lamps; and one CFL G25 lamp. The results from previous benchmark testing of lamp types considered in this study are included in Appendix C.

## Supplemental LED Replacement Lamp Data

### ENERGY STAR

LED replacement lamps fall under the purview of the ENERGY STAR Program Requirements for Integral LED Lamps.<sup>10</sup> Some requirements are separated by lamp type—omnidirectional, directional, decorative, or non-standard—whereas others apply to all lamp types. Relevant criteria are shown in Table 2. Program requirements beyond the scope of the LM-79-08 testing conducted by CALiPER are not included.

### LED Lighting Facts

As of January 2012, over 4,000 products were listed by LED Lighting Facts, including 153 A lamps,<sup>11</sup> 7 G25 lamps, 37 MR16/PAR16 lamps (tested at 120 V), 149 PAR20/R20 lamps, and 351 PAR30/R30 lamps. Summary statistics for these products are provided in Table 3. Data obtained from LED Lighting Facts are more representative of the full range of currently available products because it includes many recently listed products. However, since participation in the LED Lighting Facts program is voluntary, it does not necessarily include all products. Further,

**Table 2. ENERGY STAR Program Requirements for Integral LED Lamps (v1.4).** Only criteria relevant to CALiPER testing of LED replacement lamps are shown. Values listed are minimums, where applicable. ENERGY STAR does not differentiate based on the specific size or voltage of a product, unless noted.

Lamp Type	Initial Output (lm)	Efficacy (lm/W)	Power Factor	CRI	R <sub>g</sub>	Nominal CCT (K)	D <sub>uv</sub>
Omnidirectional (A19)	200 = 25 W Incandescent	50 ( $< 10$ W)	0.70 ( $> 5$ W only)	80	0		
	325 = 35 W Incandescent					2700	0.000 ± 0.006
	450 = 40 W Incandescent					3000	0.000 ± 0.006
	800 = 60 W Incandescent	3500				0.000 ± 0.006	
	1,100 = 75 W Incandescent	4000				0.001 ± 0.006	
	1,600 = 100 W Incandescent						
Decorative (G)	70 = 10 W Incandescent	40	0.70 ( $> 5$ W only)	80	0	2700	0.000 ± 0.006
	90 = 15 W Incandescent					3000	0.000 ± 0.006
	150 = 25 W Incandescent					3500	0.000 ± 0.006
	300 = 40 W Incandescent					4000	0.001 ± 0.006
	500 = 60 W Incandescent						
Directional (MR, PAR, R)	No Requirement (Uses center beam intensity)	40 ( $\leq 20/8$ Dia.)	0.70 ( $> 5$ W only)	80	0	2700	0.000 ± 0.006
						3000	0.000 ± 0.006
		45 ( $> 20/8$ Dia.)				3500	0.000 ± 0.006
						4000	0.001 ± 0.006

<sup>10</sup> As of publication, the current version was 1.4, available at:

[http://www.energystar.gov/ia/partners/product\\_specs/program\\_reqs/Integral\\_LED\\_Lamps\\_Program\\_Requirements.pdf](http://www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf)

<sup>11</sup> Although the focus of this study was A19 lamps, LED Lighting Facts groups all A lamps into one category. Thus, the data include some products larger than A19 lamps, as evidenced by the high maximum lumen output shown in Table 3.

**Table 3. LED Lighting Facts data for product types considered in the second retail replacement lamp study (2011).**  
Data downloaded January 2012.

Shape Category	Number of Products		Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)	Power Factor	CRI	CCT (K)
<b>A</b>	<b>153</b>	<b>Minimum</b>	97	2.0	26	0.32	56	2607
		<b>Mean</b>	524	8.5	60	0.81	80	3584
		<b>Maximum</b>	2,477	30.2	97	1.00	92	7177
<b>G25</b>	<b>7</b>	<b>Minimum</b>	80	2.3	29	0.94	80	2700
		<b>Mean</b>	189	4.3	40	0.94	83	2886
		<b>Maximum</b>	435	9.0	52	0.94	86	3000
<b>MR16<sup>1</sup></b>	<b>37</b>	<b>Minimum</b>	60	1.6	27	0.50	73	2696
		<b>Mean</b>	199	4.2	47	0.63	81	3760
		<b>Maximum</b>	392	6.5	71	0.97	87	6510
<b>PAR20</b>	<b>149</b>	<b>Minimum</b>	155	3.0	22	0.49	65	2600
		<b>Mean</b>	337	7.1	48	0.79	82	3367
		<b>Maximum</b>	818	11.2	87	0.98	95	7783
<b>PAR30</b>	<b>351</b>	<b>Minimum</b>	292	6.0	30	0.51	33	2662
		<b>Mean</b>	613	11.8	52	0.82	82	3428
		<b>Maximum</b>	1,100	20.4	88	1.00	95	7783

Notes:

1. Includes only products tested at 120 V.

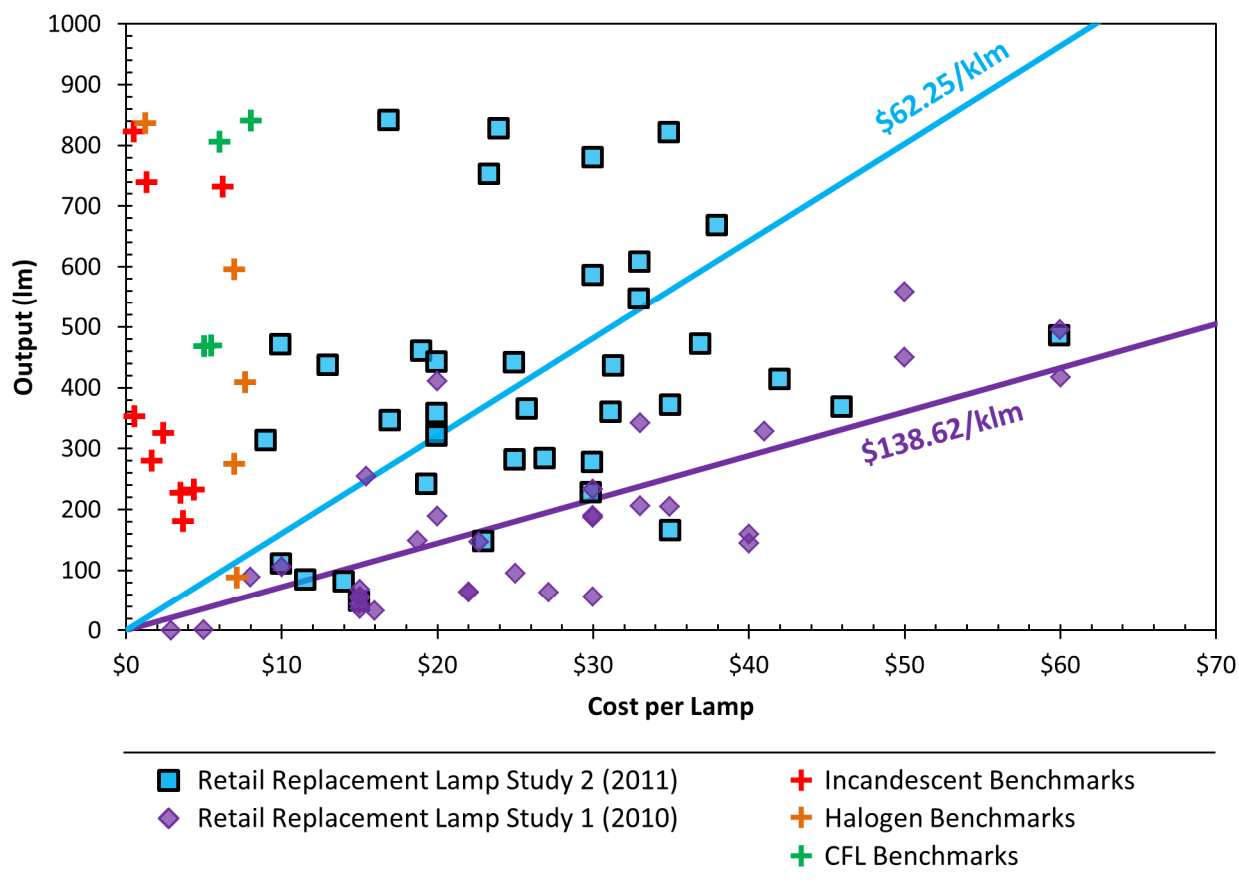
manufacturers can manually deactivate product listings that are no longer available, but because there is not yet an automatic expiration of product listings, the database may include products that are no longer sold or that have been subsequently upgraded—future upgrades are expected to address this issue.

## 5 Analysis

### Cost

Product price was intentionally omitted as a factor in determining which products to test, but it is one of the most important elements of the CALiPER retail replacement lamp testing initiative.<sup>12</sup> It is well recognized that LED products are becoming less expensive, but little citable information is available. Adjusting to consider only the products tested in both studies,<sup>13</sup> between the purchase dates in August 2010 and November 2011 the mean cost per 1,000 lumens (kilolumen) dropped from \$138.62 to \$62.25 (see Figure 1). Additionally, the cost per lumen per watt dropped from \$0.69 to \$0.48 (see Figure 2). These changes show substantial progress, but there is more to the story: the mean purchase price changed from \$30.23 to \$26.01, indicating that performance gains were more substantial than price reduction. Correspondingly, the mean input power increased from 5.1 W in 2010 to 7.6 W in 2011. In addition to these overall numbers, the cost breakdown for each lamp type is shown in Table 4, and additional comparisons between 2011 and 2010 are shown in Appendix D.

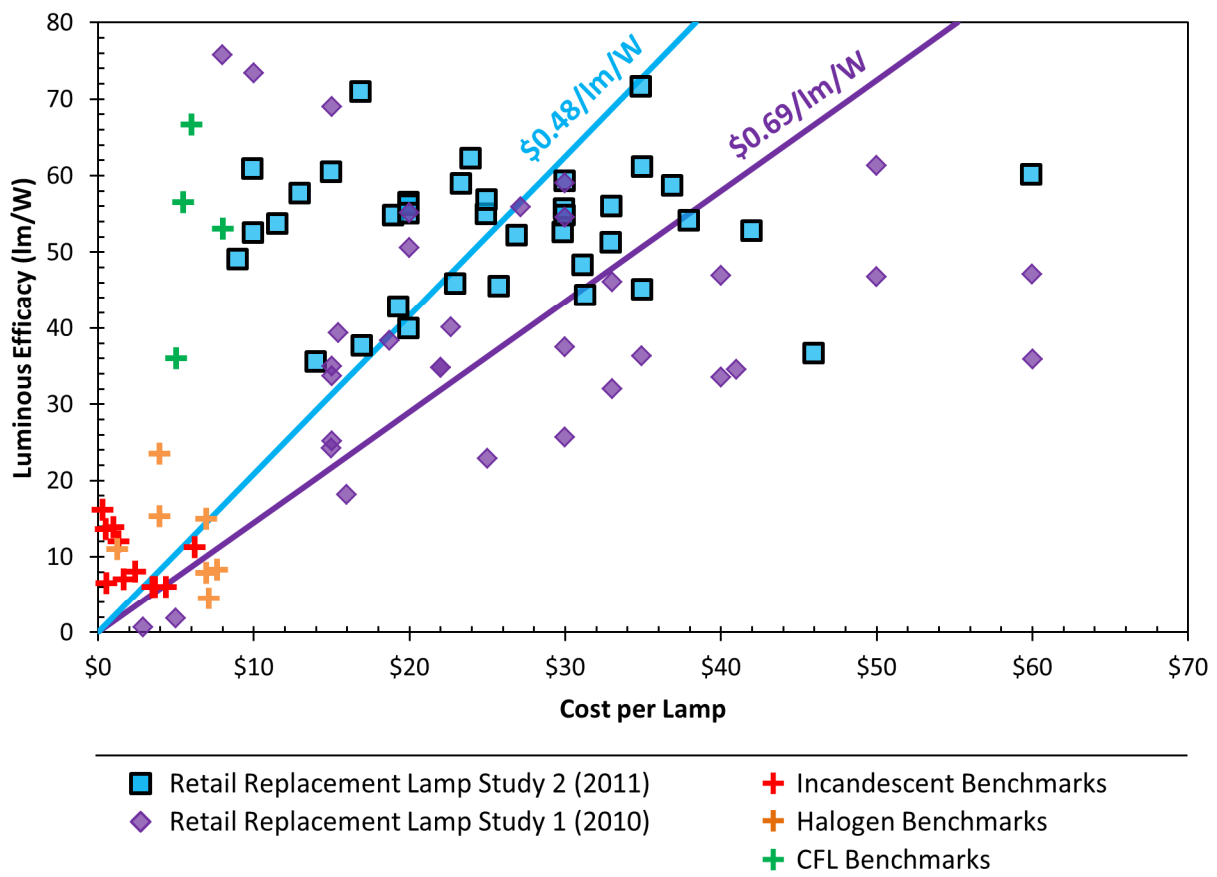
The effect of changing prices is difficult to determine. Although it is clear that consumers were getting more for the money in 2011 than 2010, the minimum and maximum prices for the samples of products that were



**Figure 1. Lumen output versus cost per lamp.** In general, the products tested had more lumen output at a given purchase price. This chart includes all products tested in each study, as well as several conventional benchmark products. The trend lines are based on the mean price per lumen of common product types.

<sup>12</sup> Price is not examined by CALiPER outside of the retail replacement lamp studies.

<sup>13</sup> Only A19, (120 V) MR16, PAR20, and PAR30 lamps were considered when comparing the two studies.



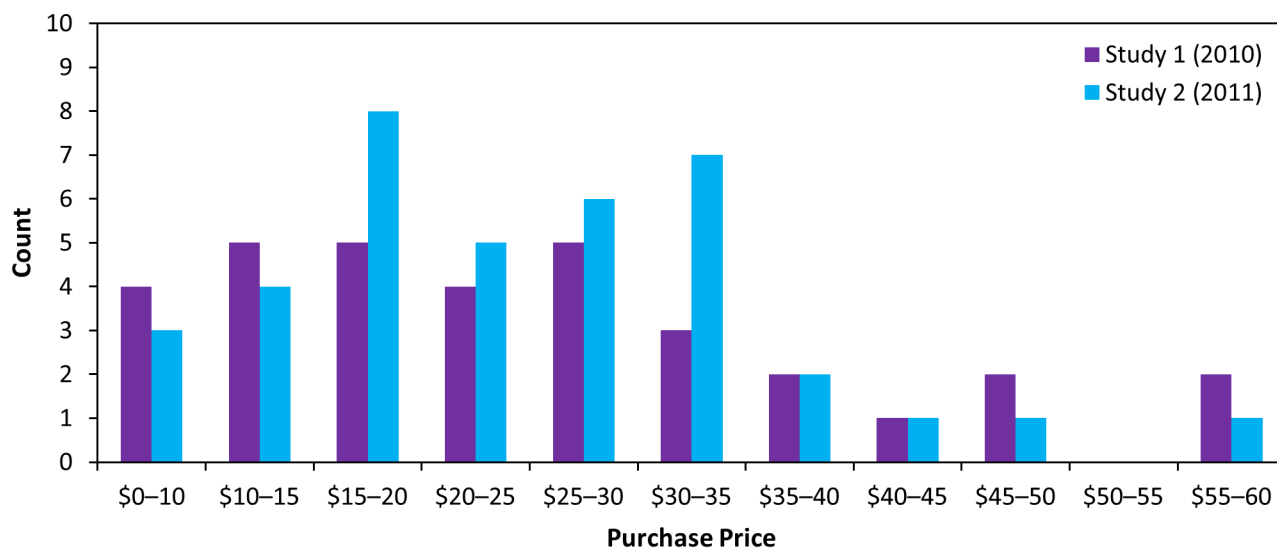
**Figure 2. Luminous efficacy (lm/W) versus cost per lamp.** In general, the products tested had a higher efficacy at a given purchase price. This chart includes all products tested in each study, as well as several conventional benchmark products. The trend lines are based on the mean price per lumen per watt of common product types.

**Table 4. Minimum, mean, and maximum prices by lamp type for products purchased in 2011 and 2010.**

		A19	MR16 (120 V)	MR16 (12 V)	PAR20	PAR30	G25	B10
Retail Lamp Study 2 (2011)	Minimum	\$8.99	\$14.99	-	\$10.00	\$16.99	\$14.00	-
	Mean	\$21.41	\$24.89	-	\$22.82	\$35.57	\$25.05	-
	Maximum	\$42.00	\$34.98	-	\$32.98	\$59.98	\$34.98	-
Retail Lamp Study 1 (2010)	Minimum	\$14.99	\$7.99	\$14.99	\$15.42	\$19.99	-	\$9.99
	Mean	\$25.99	\$20.18	\$24.98	\$28.32	\$45.84	-	\$15.74
	Maximum	\$39.99	\$29.98	\$29.98	\$34.88	\$59.99	-	\$21.99

purchased remained relatively constant. That is, there were no less expensive alternatives compared to earlier testing. Further, there was not a greater percentage of products in the lower portion of the price range (see Figure 3), and the less expensive products still tended to not perform as well.

The trend toward high lumen output products has been ongoing for several years, and the disappearance of products with lower lumen output is potentially associated. The availability of a full range of products—having



**Figure 3. Histogram of purchase price for the first (2010) and second (2011) CALiPER retail replacement lamp studies.** All products from both studies are included in this chart, totaling 33 for Study 1 and 38 for Study 2.

multiple lumen packages (and distributions) in one product family—would provide consumers with a variety of alternatives to lamps they are trying to replace. This may also introduce some lower cost products that maintain high levels of performance in other areas, such as color quality and power factor.

The mean purchase price for LED replacement lamps was still considerably higher than for comparable CFL lamps, which is likely a deciding factor for many consumers. For people seeking to test new technology, people who are dissatisfied with CFL lamps, or people with specific needs that CFL lamps cannot meet, there may be other incentives to purchase LED lamps. Further, the rated lifetime of LED lamps is generally longer than for CFL lamps, meaning an LED product may be favored if evaluated using lifetime cost; however, some consumers may not perform this type of calculation. Additionally, they may be hesitant to purchase a product with an extended life expectancy because they are unfamiliar with such a standard in the lighting market, and because the technology is still developing.

### Lumen Output and Efficacy

This study included a variety of products intended for different applications. Thus, it is best to consider lumen output and efficacy performance separately for each product type. In this analysis, past CALiPER data includes results from the first retail replacement lamp study as well as standard CALiPER testing. Note that some previously tested products are now several years old and may not represent state-of-the-art performance. The year of purchase for CALiPER-tested products is denoted by the first two digits of the identification number.

#### A19 Lamps

The A19 lamps tested for this study had output ranging from 84 to 841 lumens and input power ranging from 1.6 to 13.3 W (49 to 71 lm/W). The lumen output range is very comparable to other CALiPER test data, but the mean of 514 lumens is substantially higher than the 368 lumens measured in previous testing. Generally, there are fewer products with low lumen output appearing in retail stores; it is likely that they are being replaced with upgraded, higher output products.

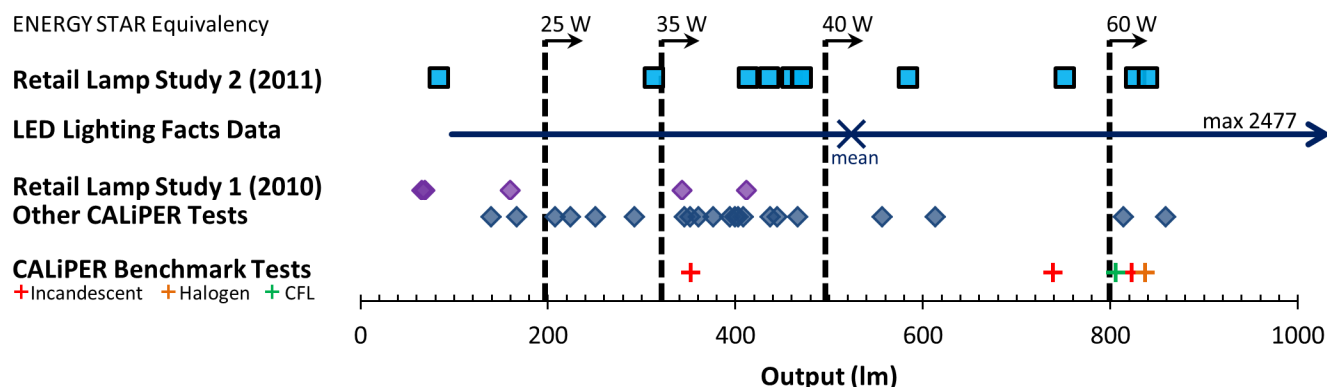
In contrast with the 2010 study, some LED products purchased from retail stores in 2011 were truly equivalent in lumen output to 60 W incandescent lamps. In the survey of products conducted before purchasing, the

maximum output was 950 lumens; notably, this was for a product with a high CCT (4900 K). As shown in Figure 4, some A lamps listed by LED Lighting Facts have very high lumen output, but the actual size, shape, and CCT of these products are not documented—many likely exceed the dimensional tolerances for A19 lamps. The next incandescent equivalency levels to be reached by retail lamps are 1,100 lumens (75 W) and 1,600 lumens (100 W).<sup>14</sup> One A21 lamp noted in the pre-purchase product survey was approximately equivalent to a 75 W incandescent lamp, but in general, products reaching these performance levels were not available through retail channels at the time.

The efficacy of the A lamps tested for this study fell within a narrow range, 49 to 71 lm/W, which is much smaller than the range for the 26 products previously tested by CALiPER (31 to 97 lm/W),<sup>15</sup> as shown in Figure 5. Several of the lowest efficacy products previously tested were purchased in 2008, whereas the highest was purchased in 2011. The range in efficacy for products listed by LED Lighting Facts is also wide, but the mean of 60 lm/W is very similar to the mean for the retail replacement lamps purchased in 2011 (58 lm/W). Thus, in general, the products found in retail stores could be considered average; retailers may be screening out poorly performing products—or the worst may have been discontinued—and the best performing products may be too costly.

All but one product (RT72) met the ENERGY STAR criterion of 55 lm/W (for lamps  $\geq 10$  W) or 50 lm/W (for lamps  $< 10$  W). RT72 was also the least expensive lamp, costing \$8.99 at the store where it was purchased. The mean efficacy of the A lamps was the highest of all the lamp types considered in this study. Likewise, the ENERGY STAR efficacy requirement is also the highest.

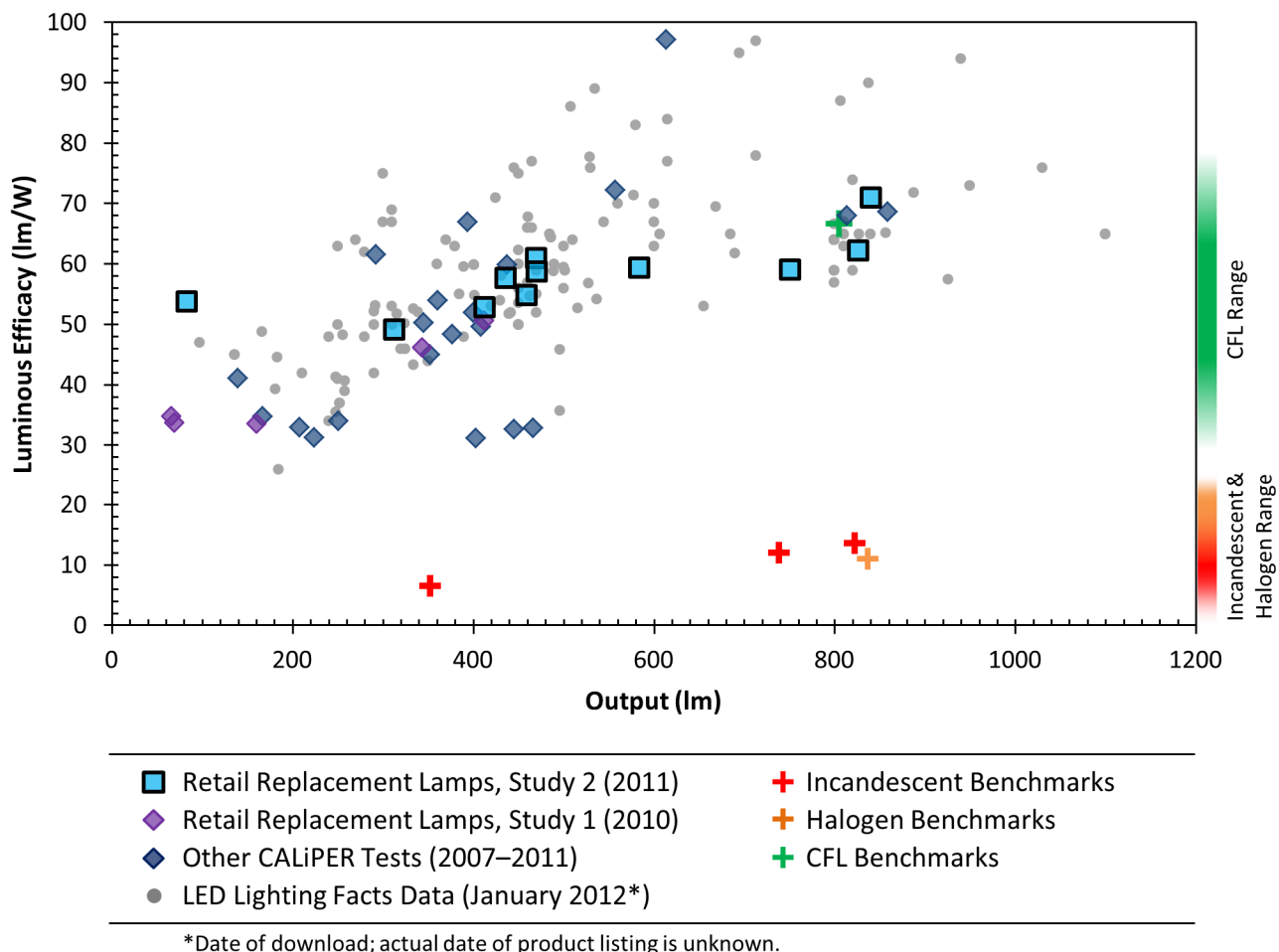
Although not a focus of this report, spatial distribution of light is an important characteristic that should not be overlooked. The luminous intensity distributions of some LED A lamp replacement products are not similar to the omnidirectional output of conventional products, potentially leading to consumer dissatisfaction. Taken by itself, lumen output does not provide enough information to choose a good replacement for a conventional A lamp. Because luminous intensity distribution was not measured, evaluations in this report are somewhat incomplete.



**Figure 4. Lumen output of LED A lamps compared to conventional benchmarks.** The products tested for the second retail replacement lamp study had a wide range of lumen equivalencies, extending up to 60 W. The products tested for the first retail replacement lamp study only reached 35 W. The “Other CALiPER tests” category includes all LED A lamps tested in the regular CALiPER program; these products were purchased between 2007 and 2011. LED Lighting Facts data extends beyond the scale of the chart.

<sup>14</sup> The listed equivalency levels are from ENERGY STAR. Other programs may have different established thresholds, because the output of incandescent lamps at any given wattage is variable.

<sup>15</sup> The 26 A lamps previously tested by CALiPER include products from regular testing as well as the first retail replacement lamp study. These products were purchased between 2007 and early 2011. The date of purchase for each regular CALiPER product corresponds to the first two digits of the identification number.



**Figure 5. Efficacy versus lumen output of LED A lamps compared to conventional benchmarks.** The A lamps tested for the second retail replacement lamp study covered a wide range of lumen output and generally had efficacies in the middle of the range for the other LED data sets. Two products listed by LED Lighting Facts with higher lumen output are not shown on the chart.

### G25 Lamps

Although G25 lamps are typically classified as decorative (e.g., by ENERGY STAR), they are sometimes used for general ambient illumination. CALiPER had not tested any G25 lamps prior to this study, and LED Lighting Facts only listed a handful of G25 products at the time the data were downloaded.

In general, the G25 lamps drew less power than the A lamps, ranging from 2.3 to 9.8 W with a mean for the five products of 7.2 W. Having efficacies between 36 and 56 lm/W (mean 47 lm/W), they produced between 81 and 442 lumens (mean 354 lumens).

ENERGY STAR requirements are lower for G25 lamps, with 300 lumens considered equivalent to a 40 W incandescent lamp. Four of the five lamps met this criterion, but none reached the 500-lumen threshold for a 60 W incandescent G25 lamp. The same four products met the ENERGY STAR efficacy minimum, as well as all other ENERGY STAR criteria that were measured for CALiPER.

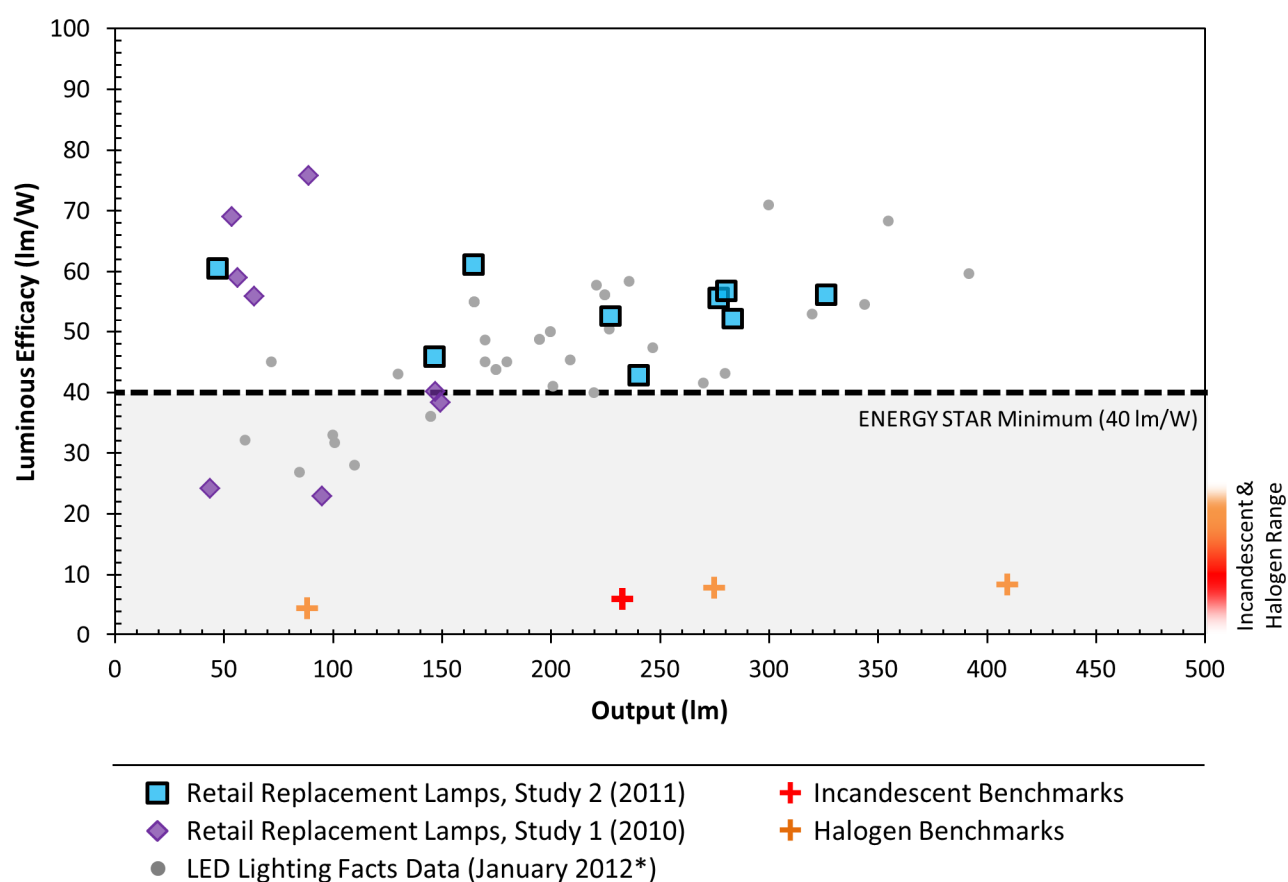
### MR16 Lamps

MR16 lamps are commonly operated at 12 V with a GU5.3 pin base, but some—especially those sold in retail stores—are operated at 120 V with a medium screw or GU10 base. Reproducing the small form factor of MR16

lamps can be a challenge for LED products, which must include electronic components and a thermal management system. LED products in this approximate size (2-inch diameter), are often arbitrarily labeled as MR16s, PAR16s, or R16s, with no distinguishable performance differences. The form factor may shift accordingly, but since there is usually no MR, PAR, or R type reflector—the LEDs often use different optical systems—performance is generally similar. For the second retail replacement lamp study, only 120 V lamps were considered—this qualification was not made during the first retail replacement lamp study. The only previous CALiPER testing of 120 V MR16 lamps was for the first retail replacement lamp study.

For directional lamps, center beam candlepower (CBCP) is often a more useful metric than total lumen output. Notably, CBCP is highly dependent on the beam angle of the lamp. As with the A lamps, luminous intensity distribution was not measured, nor was it considered during the selection process. Consequently, a comprehensive analysis of these products cannot be performed. However, the improvement versus earlier testing based on other metrics is still noteworthy.

The 120 V MR16 products tested had a mean output of 222 lumens at an efficacy of 54 lm/W, which is a significant progression from the first retail replacement lamp study (134 lumens, 45 lm/W).<sup>16</sup> The relationship



**Figure 6. Efficacy versus lumen output of 120 V LED MR16 lamps compared to conventional benchmarks.** The MR16 lamps tested for the second retail replacement lamp study covered a wide range of lumen output and generally had efficacies in the middle to high portion of the range for the other LED data sets. All products met the ENERGY STAR minimum efficacy of 40 lm/W.

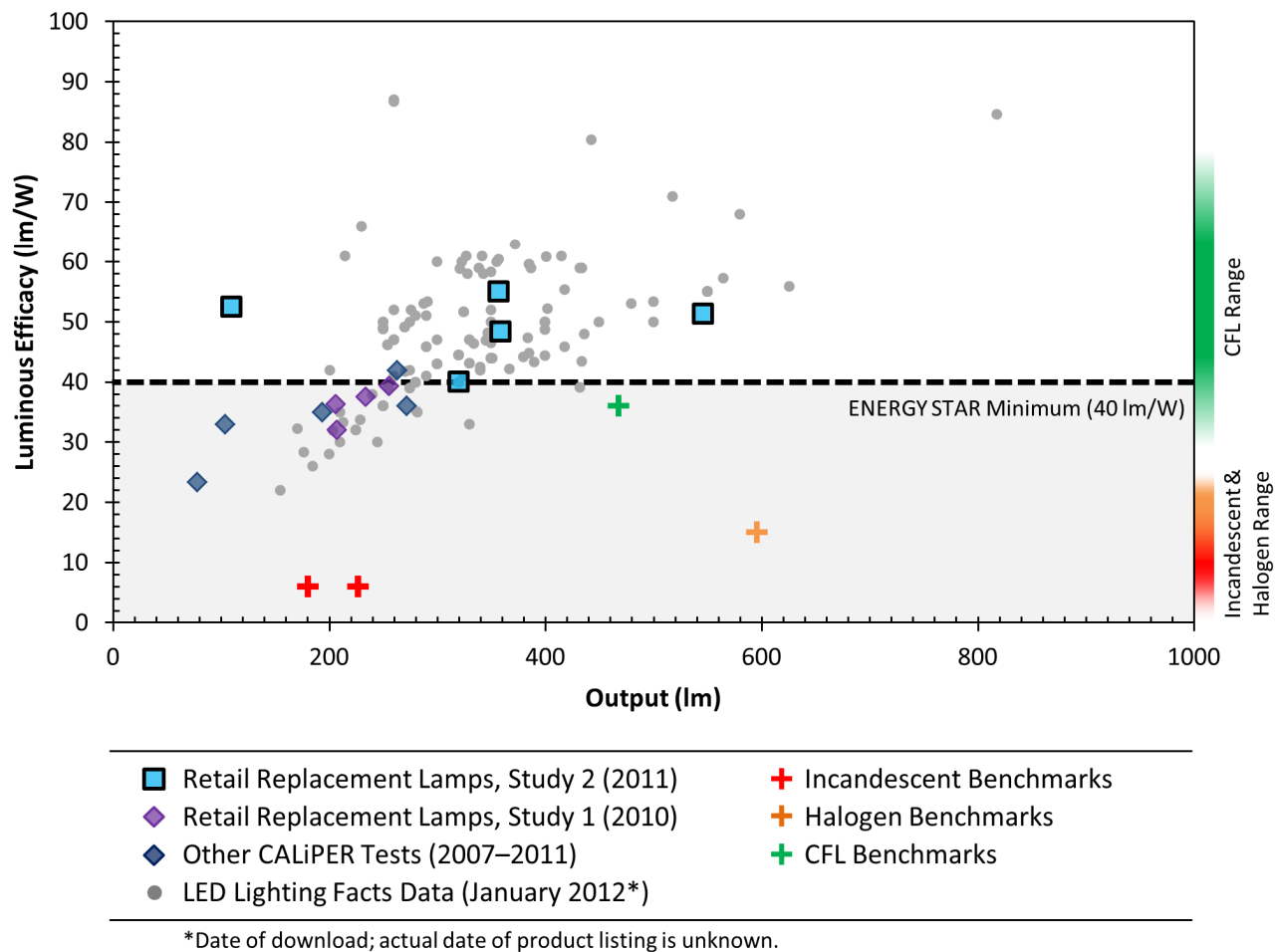
<sup>16</sup> These tabulations included only the 120 V MR16 products from the first retail replacement lamps study. The 12 V products were excluded.

between lumen output and efficacy is shown in Figure 6. Four of the products (RT51, RT55, RT59, and RT71) produced more lumen output than the 35 W, 120 V MR16 benchmark (BK 11-92); however, one product emitted only 48 lumens, which is not adequate for many applications. There were no products tested with lumen output equivalent to a 50 W, 120 V incandescent MR16 lamp.

Regardless of lumen output, the efficacies of the LED MR16 lamps tested as part of this study are favorable. All the products met the ENERGY STAR criterion of 40 lm/W and offer significant energy savings compared to incandescent or halogen lamps. The 120 V MR16 category lamps purchased at retail stores tended to be on the high end of the efficacy range for similar products listed by LED Lighting Facts, but were not the most efficacious.

**PAR20 Lamps**

Five PAR20 lamps were tested for the 2011 retail replacement lamp study, with output ranging from 110 to 547 lumens and input power ranging from 2.1 to 10.7 W (40 to 55 lm/W). Much as for MR16 lamps, the products in this category may include both PAR20 and R20 lamps, although all the lamps purchased for this study were labeled as PAR20s. As shown in Figure 7, the most recently tested lamps have improved efficacy and lumen output compared to products previously tested by CALiPER. They fall in the middle of the range of products listed by LED Lighting Facts.



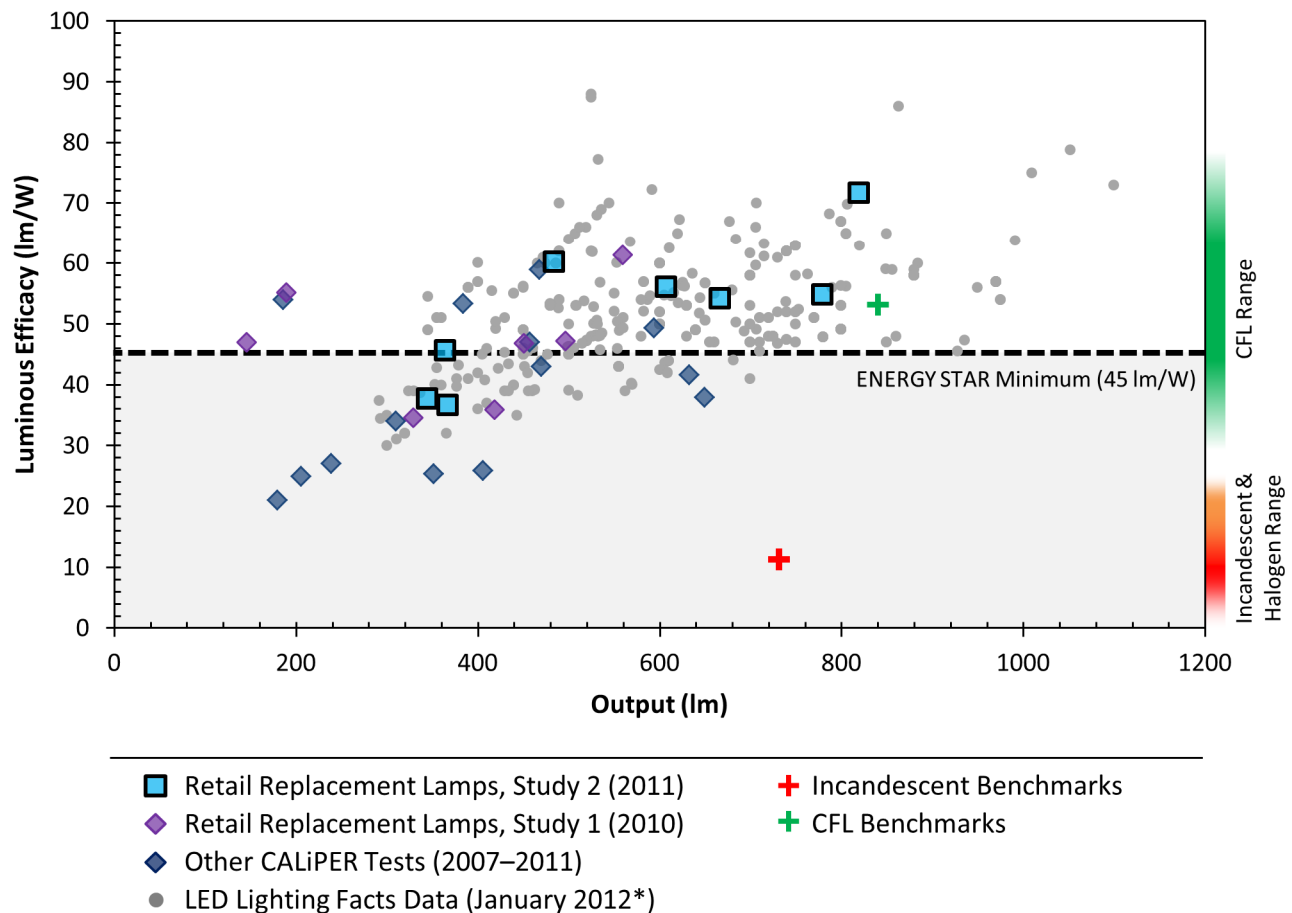
**Figure 7. Efficacy versus lumen output of LED PAR20 lamps compared to conventional benchmarks.** The limited sample of PAR20 lamps tested for the second retail replacement lamp study covered a wide range of lumen output and generally had efficacies in the middle of the range of LED Lighting Facts data, but higher than other products previously tested by CALiPER. All five products met the ENERGY STAR minimum efficacy of 40 lm/W.

The wide range of input power for the five PAR20 lamps tested is indicative of the variety of LED products consumers may find. For less knowledgeable purchasers, it would be possible to choose a less expensive lamp that only produces 110 lumens (e.g., RT67, which cost \$10.00), even though a lamp that produces more lumens may actually be equivalent to the conventional lamp being replaced. In essence, the availability of less expensive, lower performance products on retail shelves may lead to dissatisfaction for uninformed buyers.

### PAR30 Lamps

PAR30 lamps are one of the more widely available LED general illumination products found in retail stores. The eight products tested had measured input power ranging from 8.0 to 14.2 W and measured output ranging from 346 to 820 lumens (37 to 72 lm/W; mean 52 lm/W). The range of output was much larger than for the PAR30 lamps tested as part of the 2010 retail replacement lamp study, which emitted between 145 and 559 lumens. This product category included a lamp that had the highest efficacy measured in this study, but also two products that failed to meet the ENERGY STAR criterion of 45 lm/W (see Figure 8).

Previous CALiPER testing—which includes the first retail replacement lamp study—of PAR30 lamps extends back to 2007, so the range in performance was substantial (21 to 61 lm/W; mean 42 lm/W). Considering only the 2010 retail replacement lamp study, the range in efficacy was 35 to 61 lm/W (mean 47 lm/W), which is still



\*Date of download; actual date of product listing is unknown.

**Figure 8. Efficacy versus lumen output of LED PAR30 lamps compared to conventional benchmarks.** The PAR30 lamps tested for the second retail replacement lamp study covered a wide range of lumen output (although slightly less than LED Lighting Facts) and generally had efficacies in the middle to high portion of the range for the other LED data sets. Six of eight products met the ENERGY STAR minimum efficacy of 45 lm/W.

lower than for the most recently tested products. Comparing the 2011 products to these performances levels suggests notable improvements in both lumen output and efficacy in just a short time. However, not all products perform at a high level, and there is room for growth; the best lamps at retail stores do not meet the lumen output or efficacy of the best performing lamps listed by LED Lighting Facts.

### **Comparison to the Broader LED Market**

Although they do not necessarily maximize the potential of LEDs, replacement lamps are an important market segment. Especially for consumers, replacement lamps will be the primary introduction to SSL technology for the foreseeable future. Even in the context of available products, the influence is apparent: 42% of products listed by LED Lighting Facts as of January 2012 were replacement lamps.

At this point in the development process, there is still great variability among LED lighting products. Considering all products listed by LED Lighting Facts, the efficacy ranges from 5 to 111 lm/W with a mean of 54 lm/W. This differential has many contributing factors, including different constraints for different product types and variable quality from different manufacturers. Further, there are often tradeoffs between various performance parameters and cost. LED Lighting Facts does not have prerequisite performance criteria for listing, but the data must have been generated using industry standard practices (i.e., IES LM-79-08) at an accredited testing laboratory.

Compared to the range in efficacy for all products listed by LED Lighting Facts, the range in efficacy for the retail replacement lamps purchased in 2011 (36 to 72 lm/W) is small; however, at 53 lm/W, the mean is very similar. The difference in minimum and maximum efficacy may be attributable to the much smaller sample size, but it may also be indicative of the type of products that are making their way onto store shelves. As another reference point, the range of efficacies for all LED products—including both luminaires and replacement lamps—tested by CALiPER in 2011 was 16 to 97 lm/W, with a mean of 51 lm/W.

### **Color Characteristics**

The color quality of LED replacement lamps is determined at the LED package level,<sup>17</sup> with little dependence on form factor or other physical attributes. With replacement lamps, especially those sold through retail stores, color quality is important to overall consumer satisfaction. As an inherently visual attribute, it is readily noticeable when the color of the light emitted by a lamp is different from the lamp it is replacing.

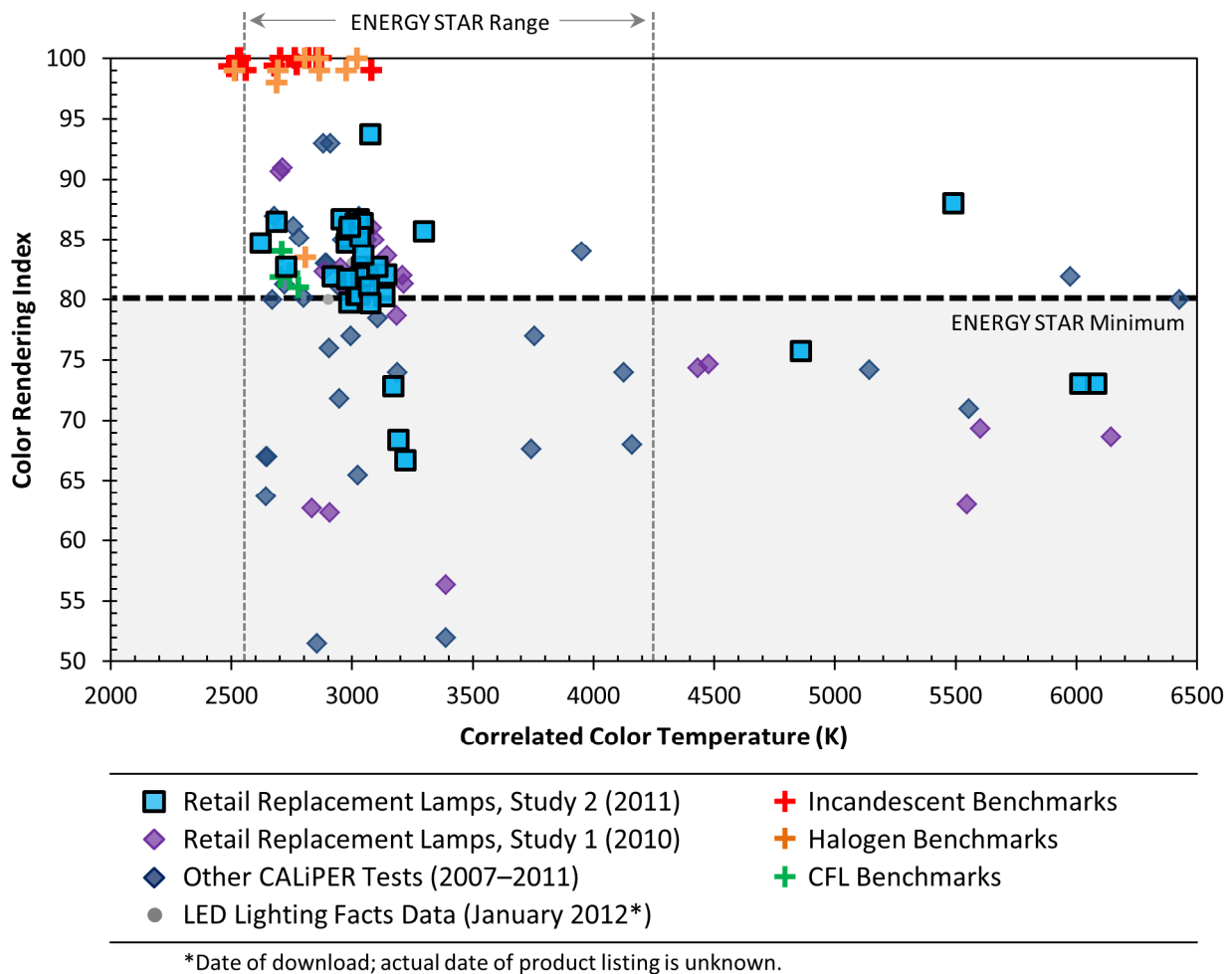
CCT and CRI were secondary considerations when selecting products, following the need to meet retailer, manufacturer, and lamp type criteria. Further, if a lamp was available in two different CCTs, the product with the lower CCT—generally more appropriate for a replacement lamp—was chosen. Given these considerations, comparing the difference in CCT between the first and second retail replacement lamp studies must be done cautiously because the samples are not necessarily representative of the overall market.

Only 4 of 38 products (11%) purchased in 2011 had a CCT greater than the maximum nominal CCT allowed by ENERGY STAR (4000 K), as shown in Figure 9. The remainder of products had a nominal CCT of either 2700 K or 3000 K. The mean price of the four higher-CCT products was \$17.55, considerably lower than the mean price of \$26.86 for the others. In contrast, the higher-CCT products cost more per kilolumen than the lower-CCT products (\$79.27 compared to \$61.93). In comparison, 7 of 31 products (23%) tested in 2010 had CCTs above nominally 4000 K.<sup>18</sup> As in 2011, these products had a lower mean cost (\$18.16) than for the lower-CCT group

---

<sup>17</sup> An LED package is the basic building block for LED lamps. It contains one or more LED dies, as well as thermal, mechanical, and electrical interfaces (but cannot be connected directly to a branch circuit). It may also have an optical component and/or encapsulant.

<sup>18</sup> The two C7 products were excluded since they are nightlights.

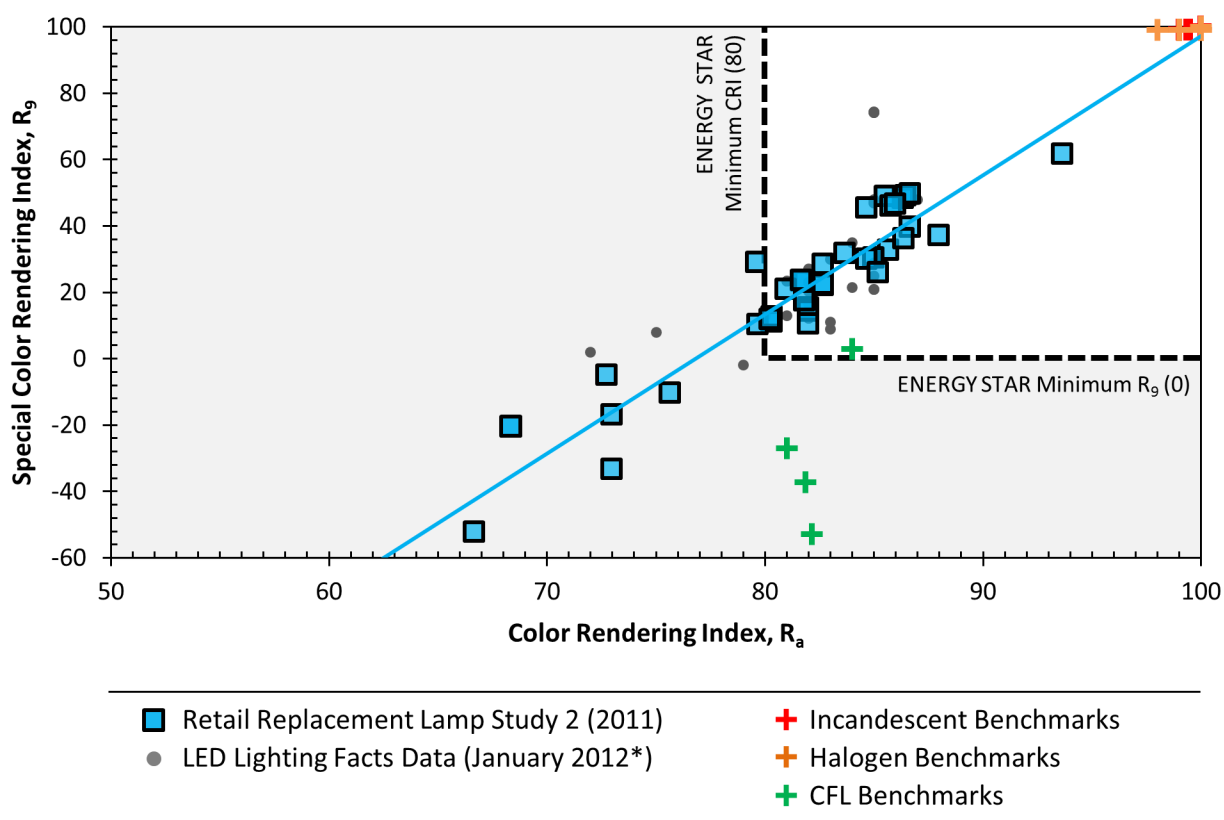


**Figure 9. Color rendering index (CRI) versus correlated color temperature (CCT) of LED replacement lamps and conventional benchmarks.** Of the 38 products tested, 34 had a nominal CCT of 2700 K or 3000 K and 32 had a CRI greater than the ENERGY STAR minimum of 80. Thirty-one products met the ENERGY STAR criteria for both metrics.

(\$30.68), but they cost less per kilolumen (\$128.76 compared to \$149.60). This result suggests that lower-cost products tended to have higher CCTs—which would be likely to surprise and perhaps disappoint a consumer looking for a direct replacement for an existing incandescent lamp—but that the prevalence of these products in the market is declining. Further, although the sample size is limited, these results suggest that lower-CCT products no longer cost more per kilolumen.

Considering CRI, the current performance level and change in performance since 2010 was similar to CCT: less expensive products tended to have CRIs less than 80, and fewer products failed to meet the ENERGY STAR criterion in the more recent study. Specifically, 6 of the 38 products (16%) purchased in 2011 and 11 of 31 products (35%) purchased in 2010 had a CRI lower than 80 (see Figure 10). The mean price for the low-CRI 2011 products was \$15.10, whereas the mean price for the low-CRI 2010 products was \$23.56. Combined, these findings demonstrate that more products were likely to meet color rendition expectations and that the potentially unsatisfactory products are increasingly likely to be the low-cost options.

Of the six products with a CRI less than 80 that were tested in 2011, three did not list a value on the packaging. Additionally, all products that did list a value for CRI (regardless of meeting the ENERGY STAR criterion) were



\*Date of download; actual date of product listing is unknown.

**Figure 10. Special color rendering index  $R_9$  versus the general color rendering index (CRI)  $R_a$  for LED products compared to conventional benchmarks.** There was a strong linear relationship between  $R_9$  and  $R_a$  ( $R^2 = 0.89$ ) for 2011 retail replacement lamp study products. All products that met the ENERGY STAR CRI requirement also met the ENERGY STAR  $R_9$  requirement.  $R_9$  data were not collected for previous CALiPER testing.

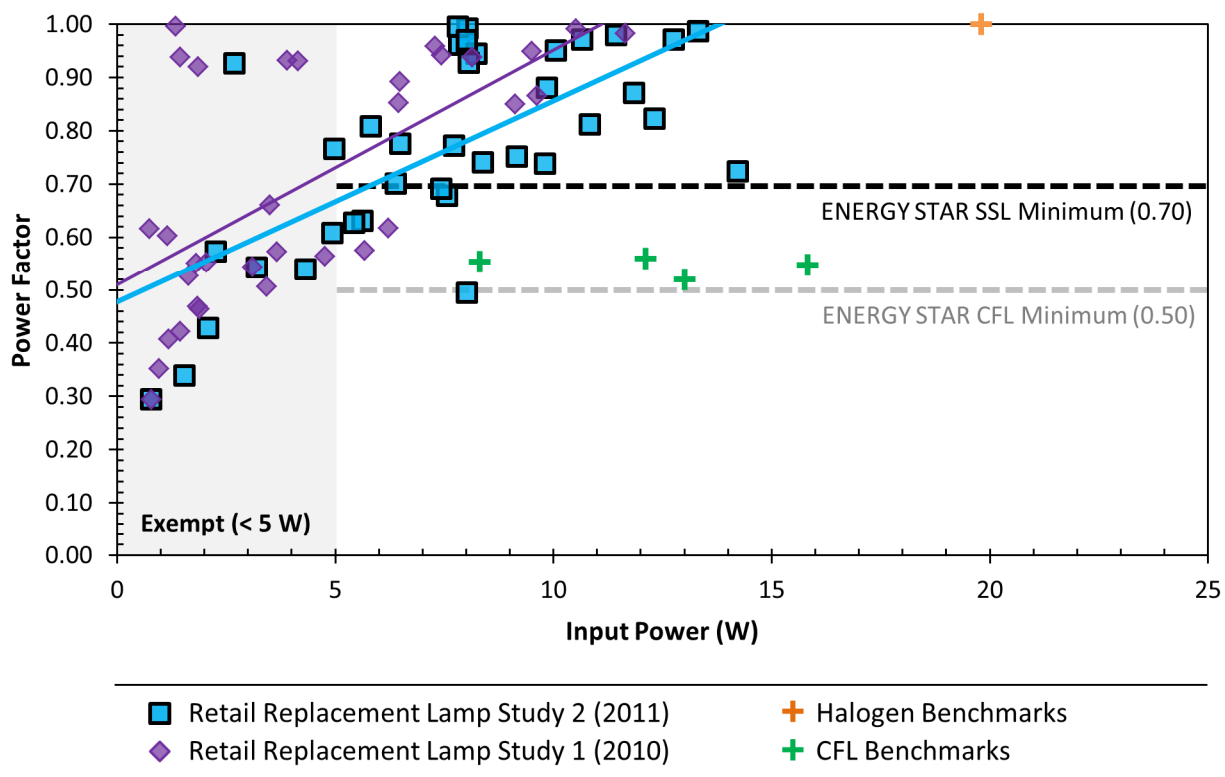
tested to be within  $\pm 10\%$  of the provided value. This suggests that consumers concerned about color quality can be confident that listed values are accurate, but should be cautious when purchasing products for which CRI is not indicated.

There was a strong linear relationship between CRI and  $R_9$  ( $r^2 = 0.89$ ), as shown in Figure 10. The six products with an  $R_9$  value less than the ENERGY STAR minimum of 0 were the same six products that failed to meet the CRI criterion. Although  $R_9$  performance is rarely reported in a way that is accessible to everyday consumers, this trend suggests that CRI may be a sufficient indicator of  $R_9$  performance for these products. Note, however, that this relationship may not exist when considering the broader LED market.

There was no discernible relationship between product type and color quality. With the exception of the small number of G25 lamps, all product types tested had at least one product with a CRI less than 80. It is also important to note that many of the products with a CRI less than 80, a CCT above 4000 K, or a  $D_{uv}$  outside ANSI tolerances were at the low end of the ranges for efficacy, lumen output, and power factor.

## Power

The mean input power for the 38 products purchased in 2011 was 7.6 W. Nine products were less than 5 W, which is the cutoff for exemption from the ENERGY STAR power factor criterion of 0.70. Similar to earlier CALiPER test results, there was a moderate linear relationship ( $R^2 = 0.44$ ) between input power and power factor



**Figure 11. Power factor versus input power for LED products compared to conventional benchmarks.** There is a moderate correlation between power factor and input power. Many products tested for the second retail replacement study met the ENERGY STAR minimum power factor of 0.70 for products drawing more than 5 W. This trend was similar to the results of the first retail replacement lamp study.

for the 2011 retail replacement lamp study products (see Figure 11)—as input power increases, power factor increases. Two of the nine products (RT55 and RT70) drawing less than 5 W had a power factor above 0.70, whereas 24 of the 29 products drawing 5 W or more had a power factor above 0.70. Overall, 18 of the products tested had a power factor greater than 0.80 and 13 had a power factor greater than 0.90. The overall range, from 0.29 to 0.99, was nearly identical to the range for products purchased for the 2010 study.

Of the six products that had a CRI lower than 80, the highest power factor was 0.70—three of the products were less than 5 W. Similarly, of the four products with a CCT greater than 4000 K, the power factors ranged from 0.29 to 0.70. Although these are small samples, there may be some correlation between products having a low power factor and products having color quality outside the typically accepted range. Further, considering only products greater than 5 W, the mean price for products with a power factor less than 0.70 was \$23.23, whereas the mean price for products with a power factor of 0.70 or greater was \$28.08. This relationship between price and performance was consistent with the relationship for other attributes examined for this study.

A noteworthy difference between lamps purchased in 2011 and lamps purchased in 2010 was claims of dimmability. Whereas only 2 of 33 products (6%) purchased in 2010 claimed to be dimmable, 24 of 38 products (63%) purchased in 2011 claimed to be dimmable. Dimming performance was not verified for either study, however.

## Size and Shape

The American National Standards Institute (ANSI) provides minimum and maximum dimensions for many lamp types including A19, PAR20, and PAR30. However, ANSI does not have established dimensional tolerances for G25 or MR16 lamps.

As measured by CALiPER, 6 of 11 A19 lamps exceeded the maximum allowable length,<sup>19</sup> whereas none were under the minimum. Similarly, 2 of 5 PAR20 lamps exceeded the ANSI specification, but none were under the minimum. In contrast, 4 of 8 PAR30 lamps were under the minimum length designated by ANSI (either PAR30L<sup>20</sup> or R30, using the label given to the lamp), but none were over the maximum. No lamps were outside the tolerances for allowable diameter.

The significance of these differences is dependent on the application and the extent to which the tolerance is exceeded. Two of the A19 lamps exceeded the limit of the specification by only 0.03 inches, meaning the difference is less likely to be problematic. In contrast, one lamp (RT46) was over by more than 0.625 inches. In some fixtures, a lamp of that size may not fit, or might visibly protrude from the aperture.

## Manufacturer Claims

LED products sold through retail stores often include several types of information on the packaging, such as published performance data—potentially within an LED or FTC Lighting Facts label—and an equivalency claim. One of the important takeaways from the first retail replacement lamp study was the need for manufacturers to present data that are more accurate.

### Did the lamps meet equivalency claims?

Of the 38 products purchased in 2011, 28 made an explicit claim of equivalency to a given wattage incandescent lamp. Notably, four products had discrepancies between the box and the retailer regarding equivalency. In three of the four cases (RT50, RT52, and RT61) the retailer made a higher equivalency claim. In one case (RT53) the retailer made a lower equivalency claim. The analyses included here are based on the manufacturer claims.

For A19 and G25 lamps, equivalency claims can be evaluated using ENERGY STAR minimum output criteria. For A19 lamps, 8 of 11 made equivalency claims, including 5 to 40 W and 3 to 60 W incandescent lamps. Only one product (RT72), had lumen output more than 5% below the ENERGY STAR minimum. This product cost \$8.99 and claimed equivalency to a 40 W lamp, but produced only 313 lumens (30% below 450 lumens), had a CRI of 76, and had a CCT of 4863 K. Interestingly, the manufacturer's listed data were very similar to the CALiPER test results, yet the equivalency claim was still made. For G25 lamps, four of the five products tested claimed equivalency to a 40 W incandescent lamp and all met that claim.

For directional lamps, establishing equivalency is much more challenging because lamps of a single form factor can have many different distributions (e.g., narrow spot or wide flood). Nonetheless, 15 of 22 directional lamps (MR16, PAR20, PAR30) tested in the 2011 study made equivalency claims, which ranged from 20 to 65 W halogen lamps. ENERGY STAR uses CBCP rather than lumen output for establishing equivalency for directional lamps, but because luminous intensity distribution is rarely reported by manufacturers and was not measured by CALiPER, that method of evaluation was not possible. LED Lighting Facts recommends that to claim equivalency, the lumen output of an LED product should be 10 times the incandescent lamp wattage equivalent (e.g., an LED lamp claiming equivalency to a 40 W lamp should produce 400 lumens). Using this methodology, 9

---

<sup>19</sup> The ANSI specification for A19 lamps is dependent on the wattage of the lamp; in evaluating the LED lamps, the equivalency claims were used to establish the appropriate comparison.

<sup>20</sup> The lamps purchased for the PAR30 category were all designated PAR30L (long neck) or R30, as opposed to PAR30S (short neck).

of the 15 products making claims failed to meet them, 1 product was under by less than 5%, and 5 products met the recommended lumen output. However, these recommended values are rudimentary and not entirely consistent with CALiPER data for conventional benchmark products.

**Did the lamps meet the published performance values?**

Although equivalency claims may be the most readily understood information for uninformed consumers, measured performance versus listed performance is also an important consideration. For some products examined in this study, performance values listed by manufacturers on packaging, on LED Lighting Facts labels, and on retailer webpages were not perfectly consistent. This can lead to considerable confusion and should be concerning to all parties involved. For this analysis, the product packaging was considered the primary source of data.

For this study, a product tested within  $\pm 10\%$  of the published performance value was considered to have met the expected performance. An interesting trend emerged in that a majority of products falling outside the  $\pm 10\%$  criterion actual had higher efficacy and/or higher lumen output than published data suggested. The consequence of this over-performance is debatable, but a consumer could be unsatisfied if a lamp emitted substantially more lumen output than expected. For example, replacement with a higher output lamp may result in glare problems.

Performance relative to listed data for lumen output and efficacy is shown in Figure 12, grouped by product type. Overall, 12 of 38 products (32%) fell outside the  $\pm 10\%$  criteria for lumen output. Notably, nine of these products *exceeded* the manufacturer listed value by greater than 10% and only three produced between 10% and 20% *fewer* lumens than listed. Three of the products exceeding the listed value did so by more than 20%. Interestingly, all the products producing more lumens than listed were directional lamps, whereas the three lamps producing fewer lumens than expected were an MR16, G25, and A19.

Given the numerous lamps producing more output than listed by the manufacturer, it is important to consider the cause. Of all the lamps tested, only five drew less power than listed and only one drew more power, based on the  $\pm 10\%$  criterion. This indicates the lumen difference is not due to overdriving the lamps. In contrast, 11 of



**Figure 12. Lumen output versus published data, grouped by lamp type.** A majority of products were measured within  $\pm 10\%$  of the listed lumen output. Only 3 of 38 products were more than 10% below the published value, and there was no trend based on product type. Nine products produced more lumen output than claimed, all of which were directional lamps.

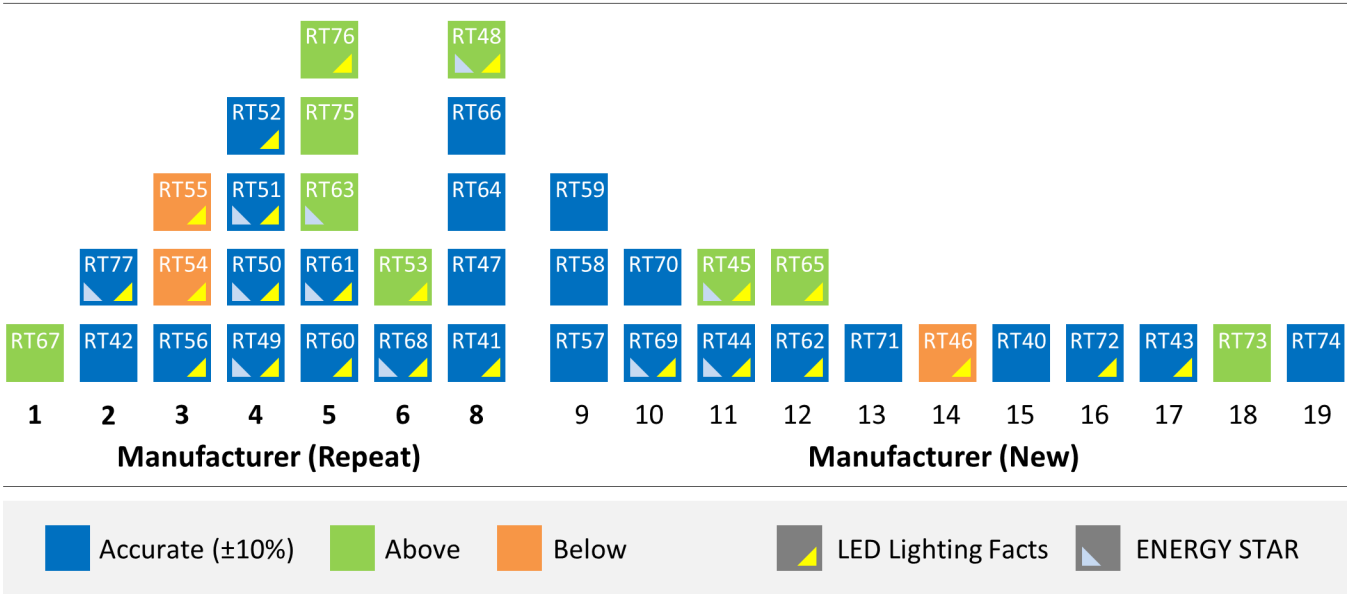
the 38 products (29%) exceeded the listed efficacy, whereas only one was lower than listed. Seven of the nine products exceeding the listed lumen output also exceeded the listed efficacy.

The directional lamps measured to be outside the tolerance came from seven different manufacturers and the data were from tests at three different laboratories—individual products were not tested at multiple laboratories. Every laboratory that tested these products had similar results. One possible explanation for the preponderance of directional lamps exceeding the listed lumen output is that manufacturers upgraded the LED packages in the lamp but did not change the packaging. Two other potential issues related to measurement of directional lamps in an integrating sphere could lead to under-measurement of lumen output: (1) the calibration of the sphere may not have been done with a directional standard; and (2) if the sphere is too small and the interior reflectance is too high, there can be correction issues leading to low readings. It is possible that manufacturers using their own test apparatus are having these issues, leading to CALiPER-measured values that are higher than listed.

Although only 25 of 38 products listed information for CRI, all the measured values were within 10% of the claimed value. Two products had a difference of four points, whereas the remainder had a difference of three points or less. These small differences are typically not meaningful.

Almost all products listed accurate CCT data, with 37 of 38 products reporting a value. One product was listed as having a CCT of 2700 K but the mean measured value was 3173 K (nominal 3000 K). Another product was listed as having a CCT of 6500 K, but instead had a CCT of 3194 K (nominal 3000 K); however, this discrepancy can be traced to packaging issues. Notably, the one product (RT40) that did not list a CCT had a measured value of 6085 K, which would likely not meet the expectations of someone replacing an incandescent lamp.

When grouped by manufacturer (see Figure 13), two stand out. Manufacturer 3 produced two of the three products with lumen output more than 10% below the listed value, whereas manufacturer 5 produced three of the nine products with lumen output more than 10% over the listed value. Six other manufacturers each had



**Figure 13. Lumen output versus published data, grouped by manufacturer.** A majority of products were measured within ±10% of the listed lumen output. Only 3 of 38 products were more than 10% below the published value. Manufacturer 3 made two of the three products that produced fewer lumens than claimed.

one product with lumen output more than 10% over the listed value. In all, nine manufacturers had all their products measured to be within tolerance of the listed value for lumen output. Nonetheless, because of the small sample size—and the fact that more than one third of the manufacturers only had one product included in the study—it is difficult to make any conclusions.

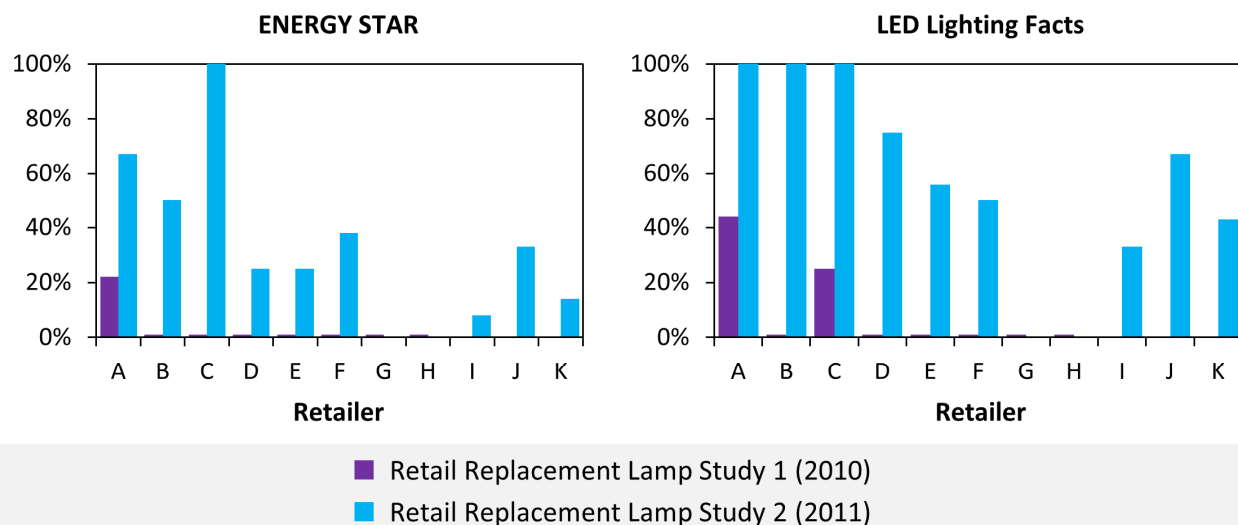
### Comparison to 2010 Retail Replacement Lamp Study

Compared to the products purchased in 2010, the products purchased in 2011 were much better at meeting manufacturer-specified performance. For example, only 63% of 2010 products met or exceeded the manufacturers' rated lumen output,<sup>21</sup> whereas in 2011 92% met that claim. Similarly, only 48% of the 2010 products met the efficacy listed, whereas 68% of the products purchased in 2011 met the listed value. Similar improvements were observed regarding listed values for CRI: in 2010, 33% of the nine products that listed a value for CRI had a different measured value, whereas all the values listed by manufacturers were accurate in 2011. Beyond the increased percentage of products meeting listed performance, a greater percentage of products that were purchased in 2011 provided information for the metrics considered.

### Product Labeling

The number of products achieving ENERGY STAR qualification or being listed by LED Lighting Facts was substantially higher for products purchased in 2011 compared to 2010. In the most recent testing, 11 of 38 products (29%) were ENERGY STAR qualified versus 2 of 33 products (6%) purchased in 2010 (see Figure 14). Similarly, 23 of 38 products (61%) purchased in 2011 were listed by LED Lighting Facts, whereas only 5 of 33 products (15%) from 2010 were listed. These tremendous changes suggest that both programs are gaining traction.

As of January 1, 2012, all medium screw base lamps (including LED) must carry an FTC Lighting Facts label. For the products purchased for this study, the effect of new FTC labeling requirements is apparent: 13 of 38



**Figure 14. Prevalence of ENERGY STAR and LED Lighting Facts labels.** Compared to products purchased in 2010, the products purchased in 2011 were much more likely to be ENERGY STAR qualified or listed by LED Lighting Facts.

<sup>21</sup> Four products purchased in 2010 did not list a value for lumen output; these products were not considered in the percentage calculations.

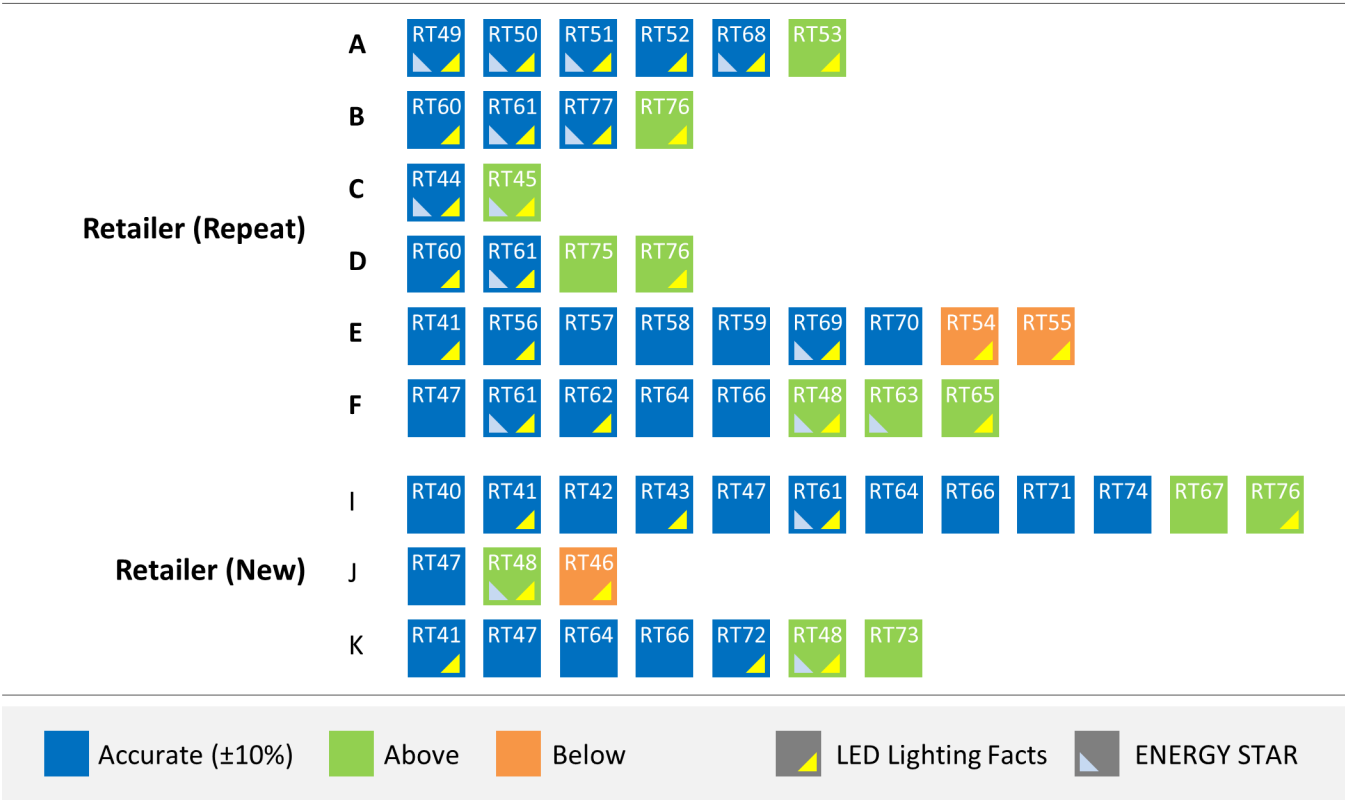
products purchased had the FTC Lighting Facts label on the package. Nine of those products were also listed by LED Lighting Facts. There is limited space on packaging, so many of these lamps provide only the identification number of their LED Lighting Facts listing, but not the full label. The FTC label includes slightly different and fewer criteria than the LED Lighting Facts label.

In past CALiPER testing, products listed by LED Lighting Facts have been much more likely than non-listed products to meet the performance claims listed by the manufacturer. However, all three of the products that produced fewer lumens than claimed were listed with LED Lighting Facts. Additionally, five of the nine products that exceeded the claimed lumen output by more than 10% were listed by LED Lighting Facts. The exact cause of this outcome is indeterminable. As the LED Lighting Facts program has grown, the need for regulation and integrity safeguards has increased. New measures to provide buyers and specifiers with a greater level of confidence will be implemented in 2012.

### Retailer Analysis

An important component of the CALiPER retail replacement lamp testing initiative is providing feedback to retailers regarding the products that are on their shelves. Thus, product performance was also grouped by retailer, as shown in Figure 15. To provide a more comprehensive analysis, any of the tested products that were found to be sold at a given retailer, regardless of actual purchase location, were attributed to that store. Thus, there are more than 38 items shown in Figure 15.

Many retailers stocked products from one or two manufacturers, but some carried products from up to eight manufacturers. Nine of the products included in this study were available at multiple retailers, with one



**Figure 15. Lumen output versus published data, grouped by retailer.** A majority of products were measured within ±10% of the listed lumen output. Only 3 of 38 products were more than 10% below the published value. Each retailer sold at least one product that was measured to have lumen output different from the listed value.

available at four different retailers. Predominantly, however, specific products were available at only one retailer. Furthermore, exclusivity often extended to an entire brand of products<sup>22</sup>—this may make it difficult for a consumer to find the best product for his or her needs. Necessitating comparison shopping at multiple retailers may in fact lead consumers to settle for a product that they will not be satisfied with, or to choose a conventional lamp instead. This is especially true because most LED replacement lamp manufacturers do not offer more than one or two products in a given form factor.

Given the overall improvement in the accuracy of manufacturer data and equivalency claims, it is not surprising that many retailers who were also considered for the first retail replacement lamp study fared better in the second study. Nonetheless, each retailer sold at least one product that did not meet the lumen output listed by the manufacturer. Additionally, although product performance was generally better compared to products purchased in 2010, some products on store shelves are still unlikely to meet consumer expectations, regardless of listed values. For example, product RT64 was an A lamp producing 84 lumens. Although this may be appropriate in a purely decorative application, it would not be effective for general ambient illumination. This caveat is often not clearly communicated on the product packaging, so retailers choosing to carry such products should consider the way they are displayed in stores and/or how they are described on their website.

---

<sup>22</sup> Some retailers rebrand products that are produced by a manufacturer. However, no products included in this study were sold under different names at different retailers.

## 6 Conclusion

---

Undoubtedly, the retail replacement lamp market progressed between the 2010 and 2011 CALiPER replacement lamp studies—both the efficacy and lumen output per dollar increased. Equally as important, however, is improvement in other areas: retailers stocked more products that performed as indicated by published data, more products included the ENERGY STAR and/or LED Lighting Facts labels, equivalency claims were more realistic, and color quality attributes were generally closer to expectations derived from conventional lamps. Nonetheless, there is room for improvement. For example, of the products with performance outside the  $\pm 10\%$  criteria, a majority actually provided more lumens than stated on the product labels. Although this is generally preferred to underperforming, it demonstrates that keeping product labeling up-to-date as products are improved can be a challenge. Further, some lamps being sold were not well suited for general ambient illumination applications; thus, purchasing the correct product still requires consumer knowledge of several important lighting metrics.

Specifically, in comparison to the first retail replacement lamp study:

- There continued to be a range in performance, but fewer products would be considered unacceptable in terms of lumen output, efficacy, and color quality.
- A much higher percentage of products performed similar to the incandescent and CFL lamps they were intended to replace.
- Many more products included a Lighting Facts label—either LED Lighting Facts or FTC Lighting Facts—or were ENERGY STAR qualified, which is likely to foster more effective consumer evaluations. Notably, the FTC Lighting Facts label does not contain all the information that is found on the LED Lighting Facts label.
- A much higher percentage of products were measured within tolerance of listed performance values, so there were fewer obvious disparities among different manufacturers and different retailers.

One of the most notable findings in this study was the substantial decrease in price per kilolumen, from \$138.62 to \$62.25 in just over one year. However, that statistic alone is not enough to indicate satisfactory improvement; quality is equally important. Although not a universal finding, less expensive LED replacement lamps were more likely to fall below ENERGY STAR thresholds for CRI, CCT,  $R_9$ ,  $D_{uv}$ , and power factor. Furthermore, there was often correlation between the products that failed to meet the criteria in those categories, as well as some relation to low lumen output and low efficacy. This trend can be both positive and negative; it could be problematic if consumers purchase less expensive products without considering performance, but it also clearly indicates that consumers will get what they pay for.

The best outcome for the future would be to have high-quality products displace the lower-quality products at low price points. Because many LED replacement lamps have reached appropriate levels of lumen output compared to conventional lamps, it is reasonable to expect that future reductions in the price per kilolumen will result from a reduction in price, rather than an increase in lumen output.

## Appendix A: Definitions

---

<b>Beam Angle</b> Degrees (°)	The angle between the two directions for which the intensity is 50% of the maximum intensity (ANSI/IES RP-16-10) or center beam intensity (ANSI C78.379-2006), as measured in a plane through the beam axis. For example, if the maximum intensity is 1000 cd, the angle at which the intensity is 500 cd is half of the beam angle. If 500 cd occurs at 20° from center beam, then the beam angle is 40°.
<b>Center Beam Candlepower (CBCP)</b> Candela (cd)	The luminous intensity at the central axis of the beam, which typically corresponds to a vertical angle of 0° (called nadir for lamps oriented downward). Although candlepower is a deprecated term, it is still widely used in this context.
<b>Correlated Color Temperature (CCT)</b> Kelvin (K)	The absolute temperature of a blackbody radiator having a chromaticity that most nearly resembles that of the light source. CCT is used to describe the color appearance of the emitted light.
<b>Color Rendering Index (CRI or R<sub>a</sub>)</b>	A measure of color fidelity that characterizes the general similarity in color appearance of objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for a sample of eight color samples illuminated with the test and reference source.
<b>D<sub>uv</sub></b>	The distance from the Planckian locus on the CIE 1960 UCS chromaticity diagram (also known as u', 2/3 v'). A positive value indicates the measured chromaticity is above the locus (appearing slightly green) and a negative value indicates the measured chromaticity is below the locus (appearing slightly pinkish). The American National Standards Institute provides limits for D <sub>uv</sub> for nominally white light.
<b>Luminous Efficacy</b> Lumens per watt (lm/W)	The quotient of the total luminous flux emitted and the total input power.
<b>Field Angle</b> Degrees (°)	The angle between the two directions for which the intensity is 10% of the maximum intensity (ANSI/IES RP-16-10) or center beam intensity (ANSI C78.379-2006), as measured in a plane through the beam axis. For example, if the CBCP is 1000 cd, the angle at which the intensity is 100 cd is half of the field angle. If 100 cd occurs at 32° from center beam, then the field angle is 64°.
<b>Input Power</b> Watts (W)	The power required to operate a device (e.g., a lamp or a luminaire), including any auxiliary electronic components (e.g., ballast or driver).
<b>Luminous Intensity Distribution</b> Candela (cd)	The directionality of radiant energy emitted by a source, which may be shown using one of several techniques. It is most often presented as a polar plot of the candelas emitted in a vertical plane through the center of the lamp or luminaire.
<b>Output</b> Lumens (lm)	The amount of light emitted by a lamp or luminaire. The radiant energy is weighted with the photopic luminous efficiency function, V(λ).
<b>Power Factor</b>	The quotient of real power (watts) flowing to the load (e.g., lamp or fixture) and the apparent power (volt amps) in the circuit. Power factor is expressed as a number between 0 and 1, with higher values being more desirable.

<b>Special Color Rendering Index <math>R_9</math></b>	A measure of color fidelity that characterizes the similarity in color appearance of deep red objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for the color sample illuminated with the test and reference source. $R_9$ and $R_a$ (CRI) are part of the same CIE Test-Color Method, but the $R_9$ color sample is not included in calculation of $R_a$ .
<b>Spacing Criterion (SC)</b>	The estimated ratio between the mounting height above the work plane and luminaire spacing necessary for a regular array of a given luminaire to produce a work plane illuminance that is acceptably uniform. For example, for a luminaire recessed into a 10-foot ceiling with a work plane that is 30 inches above the floor, if the spacing criterion is 1.4, the luminaire should be spaced no more than 10.5 feet on center ( $1.4 \times (10 - 2.5) = 10.5$ ). Spacing criterion is also referred to the spacing-to-mounting-height ratio (S/MH).
<b>Zonal Lumens</b>	The amount or proportion of lumens emitted in different vertical or horizontal regions related to a lamp or luminaire. Typically, it is expressed in vertical increments from nadir, but could also be expressed in horizontal zones [e.g., the IES Luminaire Classification System, which also defines backlight, uplight, glare (BUG) ratings].

## Appendix B: Retail Replacement Lamps, 2010

**Table B-1. Results from the first retail replacement lamp study.** Performance criteria include initial output, total power input, luminous efficacy, power factor, color rendering index (CRI), correlated color temperature (CCT), and  $D_{uv}$ . Labels indicate whether the product is listed by ENERGY STAR (ES) or LED Lighting Facts (LF).  $R_g$  data were not collected for the 2010 study.

DOE CALiPER Test ID	Shape Category <sup>1</sup>	Cost <sup>2</sup> (\$)	Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)	Power Factor	CRI	CCT (K)	$D_{uv}$ <sup>3</sup>	Labels
RT1	A19	39.99	160	4.8	34	0.56	79	3184	0.0040	
RT3	A19	32.99	343	7.4	46	0.94	81	3044	-0.0019	
RT4	A19	21.99	65	1.9	35	0.46	81	3011	0.0032	LF
RT5	A19	19.97	412	8.1	51	0.94	86	3081	0.0007	
RT34	A19	14.99	69	2.0	34	0.55	81	2970	-0.0019	
RT10	MR16	29.98	56	1.0	59	0.35	63	2832	0.0012	
RT12	MR16	14.99	54	0.8	69	0.29	69	6143	0.0059	
RT13	MR16	24.99	95	4.1	23	0.93	82	3208	-0.0073	
RT18	MR16	27.11	64	1.1	56	0.60	62	2905	0.0037	
RT20	MR16	18.72	149	3.9	38	0.93	75	4477	0.0017	
RT16	MR16	22.65	147	3.7	40	0.57	84	3144	-0.0035	
RT17	MR16	14.98	44	1.8	24	0.55	81	3214	-0.0086	
RT19	MR16	7.99	89	1.2	76	0.41	63	5545	0.0050	
RT21	PAR20	29.97	233	6.2	38	0.62	86	3050	-0.0039	
RT22	PAR20	34.88	206	5.7	36	0.58	83	2951	-0.0045	
RT23	PAR20	32.99	207	6.4	32	0.85	91	2711	0.0009	
RT24	PAR20	15.42	255	6.5	39	0.89	74	4430	-0.0012	
RT25	PAR30	59.99	418	11.6	36	0.98	56	3387	0.0039	
RT26	PAR30	59.98	496	10.5	47	0.99	80	3060	-0.0029	
RT28	PAR30	39.99	145	3.1	47	0.54	82	8107	0.0020	
RT29	PAR30	19.99	189	3.4	55	0.51	69	5601	-0.0004	
RT30	PAR30	49.97	450	9.6	47	0.87	85	3093	-0.0026	ES LF
RT31	PAR30	40.96	329	9.5	35	0.95	82	2882	-0.0045	
RT32	PAR30	49.97	559	9.1	61	0.85	91	2701	-0.0013	ES LF
RT11	MR16 12 V	14.99	36	1.4	25	0.94	78	3879	-0.0065	
RT14	MR16 12 V	29.97	191	3.5	55	0.66	87	4049	-0.0040	LF
RT15	MR16 12 V	29.98	187	7.3	26	0.96	82	2836	0.0020	
RT7	C7	4.98	1	0.7	2	0.62	80	6734	0.0103	
RT8	C7	2.88	1	1.3	1	1.00	81	8837	0.0004	
RT2	B10	9.99	106	1.4	73	0.42	67	6543	-0.0058	
RT6	B10	21.99	64	1.8	35	0.47	82	3181	-0.0032	
RT9	B10	15.97	34	1.8	18	0.92	82	3013	-0.0037	LF
RT33	B10	15.00	57	1.6	35	0.53	82	2934	-0.0028	

## Appendix C: CALiPER Testing of Conventional Benchmarks

**Table C-1. Results from CALiPER testing of conventional lamps.** Performance criteria include initial output, total input power, luminous efficacy, power factor, color rendering index (CRI), and correlated color temperature (CCT). The first two digits of the CALiPER Test ID indicate the year in which the product was purchased. All products tested are 120 V.

DOE CALiPER Test ID	Shape	Source Type	Cost <sup>1</sup> (\$)	Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)	Power Factor	CRI	CCT (K)
08-04	A19	Incandescent	0.52	353	54.6	7	1.00	99	2491
08-49	A19	Incandescent	1.32	739	61.0	12	1.00	100	2703
10-31	A19	Incandescent	0.50	823	60.6	14	1.00	100	2771
11-09	A19	Incandescent	0.31	1618	100.0	16	1.00	100	2819
11-11	A19	Incandescent	-	1694	101.0	17	1.00	100	2854
11-12	A19	Incandescent	-	1322	99.0	13	1.00	100	2871
11-25	A19	Incandescent	0.99	1245	89.8	14	1.00	100	2764
11-10	A19	Halogen	-	1550	73.0	21	1.00	100	3020
11-13	A19	Halogen	1.25	837	75.0	11	1.00	84	2805
11-14	A19	Halogen	-	1433	79.0	18	1.00	99	2974
11-15	A19	Halogen	3.97	1503	98.0	15	1.00	100	2858
11-24	A19	Halogen	3.97	1671	71.0	24	1.00	99	2863
08-27	A19	CFL	5.99	806	12.1	67	0.56	82	2703
11-94	G25	Incandescent	1.66	280	39.6	7	1.00	100	2537
11-95	G25	Incandescent	2.39	326	40.6	8	1.00	99	3081
11-93	G25	CFL	5.49	469	8.3	57	0.55	84	2708
09-08	R16	Incandescent	4.37	233	40.0	6	1.00	100	2529
11-90	MR16	Halogen	7.11	88	19.8	5	1.00	99	2514
11-91	MR16	Halogen	7.64	410	49.3	8	1.00	100	2804
11-92	MR16	Halogen	6.97	275	34.9	8	1.00	99	2693
09-05	R20	Incandescent	3.50	227	40.0	6	0.99	99	2516
09-07	R20	Incandescent	3.66	181	29.0	6	1.00	99	2560
09-09	R20	Halogen	6.97	596	41.0	15	1.00	98	2687
09-10	R20	CFL	5.00	468	13.0	36	0.52	81	2778
08-13	R30	Incandescent	6.20	732	65.0	11	1.00	99	2681
08-06	R30	CFL	8.00	841	15.8	53	0.55	82	2740

Notes:

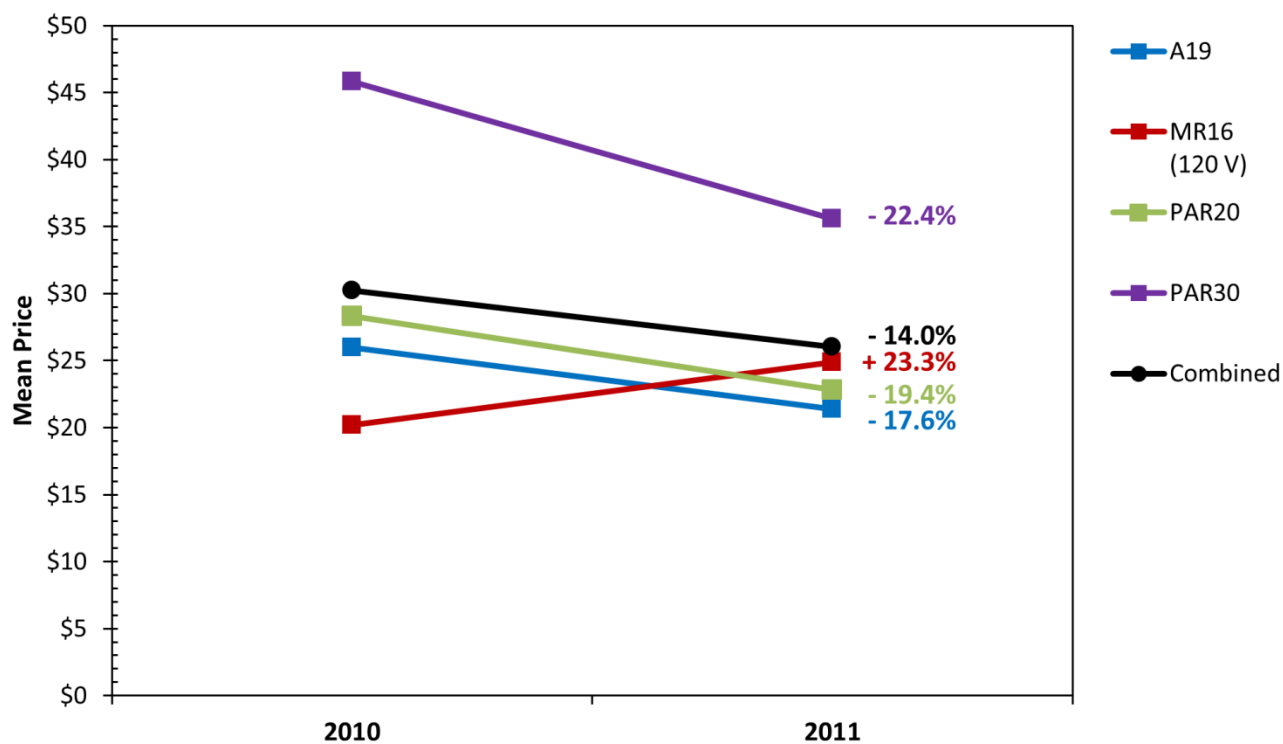
1. Cost data for products 11-90, 11-91, 11-92, 11-93, 11-94, and 11-95 are actual prices paid, whereas the other prices are estimated based on listings as of January 2012.

## Appendix D: Comparisons between 2010 and 2011 Studies

The following tables and figures demonstrate the change in performance between the 2010 and 2011 retail replacement lamp studies. Combined increases in input power and luminous efficacy resulted in greater lumen output for the 2011 products compared to the 2010 products. The performance per dollar also improved substantially. The combined data are for lamp types included in both studies. The percent change is relative to the 2010 data.

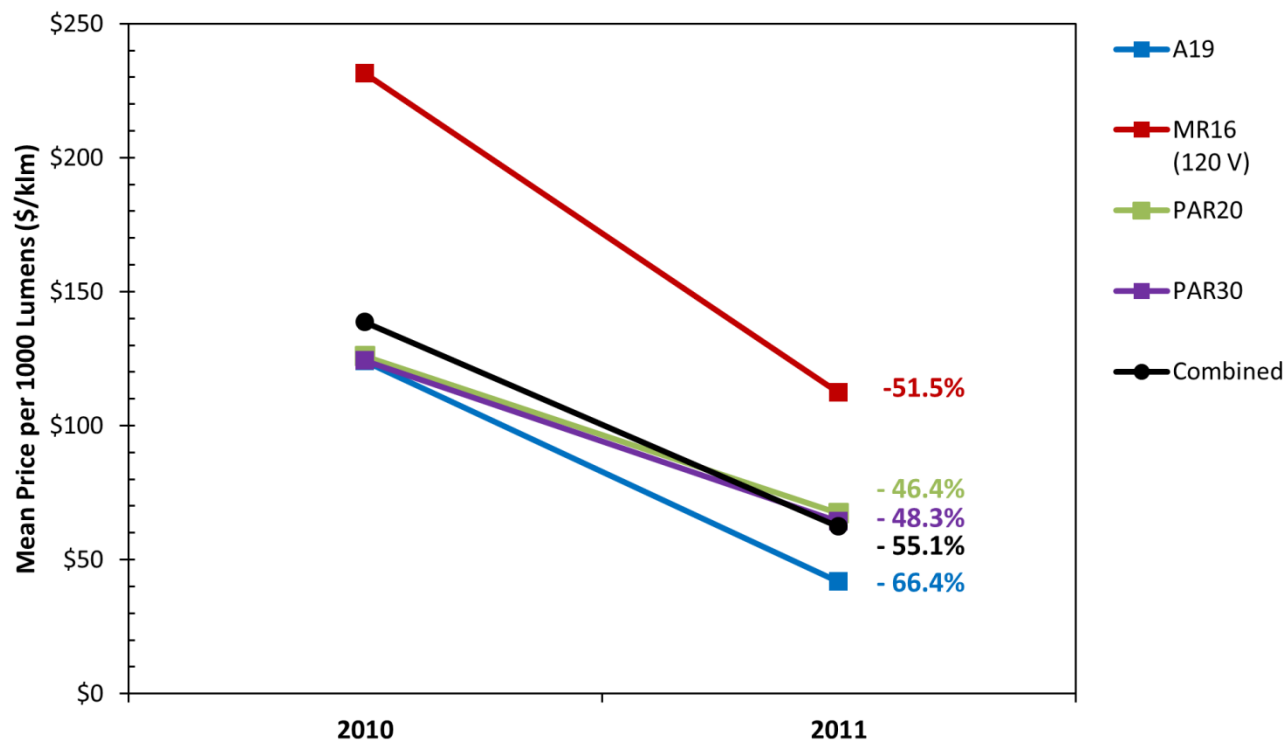
### 1. Price per Lamp

		A19	MR16 (120 V)	PAR20	PAR30	Combined	MR16 (12 V)	G25	B10
Retail Lamp Study 2 (2011)	Minimum	\$8.99	\$14.99	\$10.00	\$16.99	\$8.99	-	\$14.00	-
	Mean	\$21.41	\$24.89	\$22.82	\$35.57	\$26.01	-	\$25.05	-
	Maximum	\$42.00	\$34.98	\$32.98	\$59.98	\$59.98	-	\$34.98	-
Retail Lamp Study 1 (2010)	Minimum	\$14.99	\$7.99	\$15.42	\$19.99	\$7.99	\$14.99	-	\$9.99
	Mean	\$25.99	\$20.18	\$28.32	\$45.84	\$30.23	\$24.98	-	\$15.74
	Maximum	\$39.99	\$29.98	\$34.88	\$59.99	\$59.99	\$29.98	-	\$21.99
Change	Mean	-17.6%	23.3%	-19.4%	-22.4%	-14.0%			



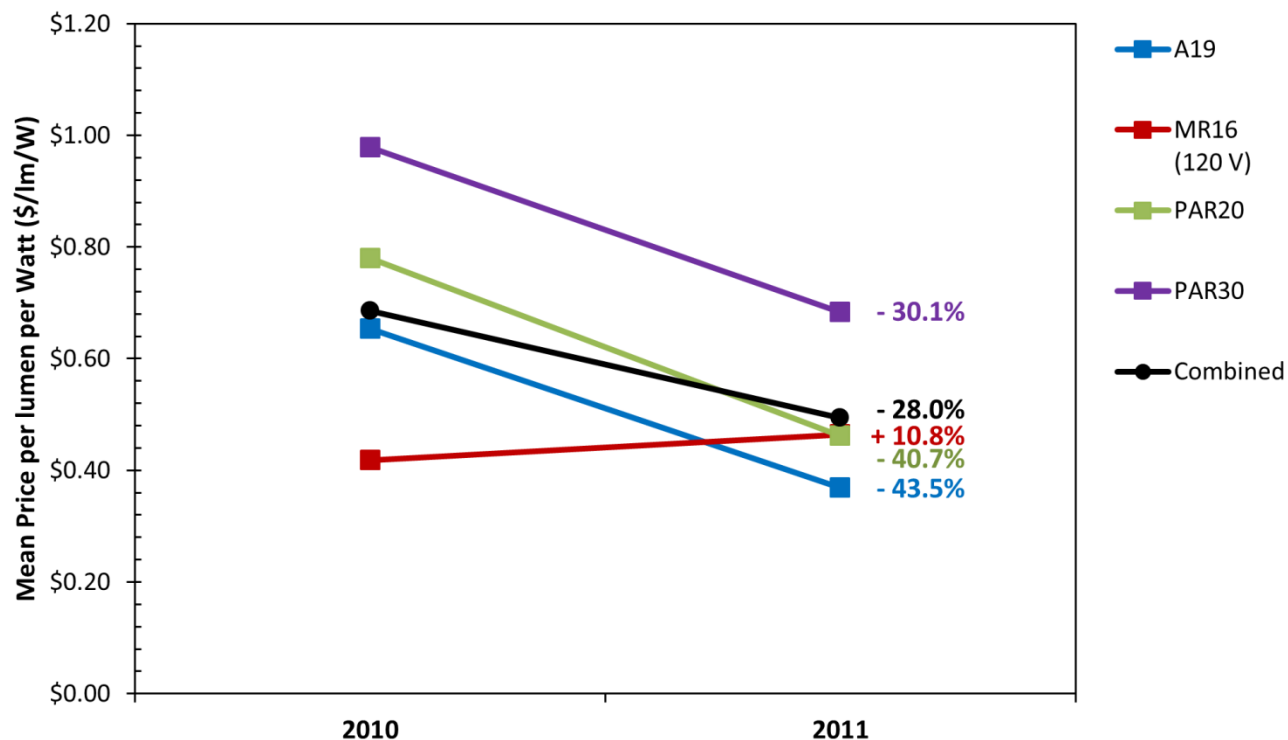
## 2. Price per Kilolumen

		A19	MR16 (120 V)	PAR20	PAR30	Combined	MR16 (12 V)	G25	B10
Retail Lamp Study 2 (2011)	Ratio of Means	\$41.65	\$112.14	\$67.35	\$64.10	\$62.25		\$70.74	
	Minimum	\$20.07	\$61.11	\$55.90	\$38.44	\$20.07	-	\$45.24	-
	Mean	\$51.76	\$138.55	\$71.19	\$70.07	\$82.81	-	\$88.17	-
	Maximum	\$137.43	\$314.48	\$90.65	\$124.98	\$314.48	-	\$172.88	-
Retail Lamp Study 1 (2010)	Ratio of Means	\$123.94	\$231.25	\$125.75	\$124.06	\$138.62	\$180.87		\$241.50
	Minimum	\$48.51	\$89.78	\$60.47	\$89.39	\$48.51	\$157.19	-	\$94.54
	Mean	\$190.01	\$276.30	\$129.53	\$138.62	\$193.71	\$243.26	-	\$293.53
	Maximum	\$336.58	\$532.19	\$169.59	\$275.16	\$532.19	\$412.57	-	\$474.36
Change	Ratio of Means	-66.4%	-51.5%	-46.4%	-48.3%	-55.1%			
Change	Mean	-72.8%	-49.9%	-45.0%	-49.5%	-57.2%			



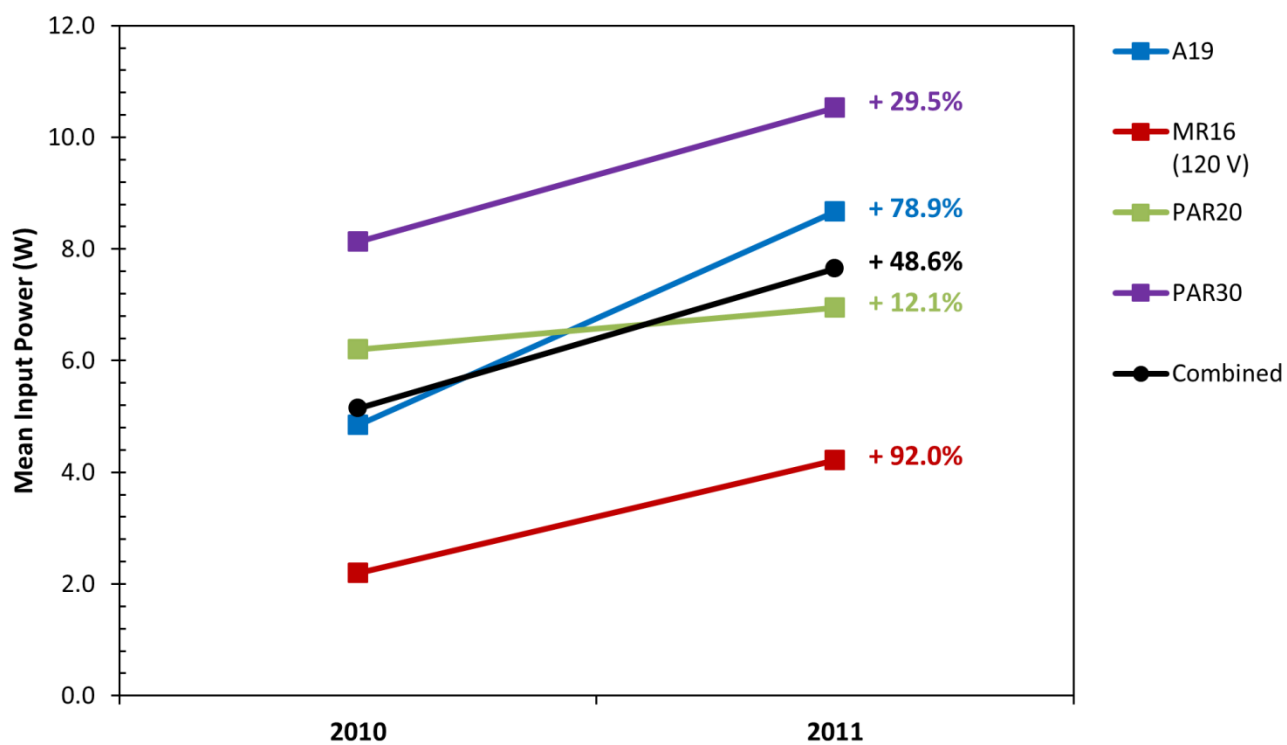
### 3. Price per Lumen per Watt

		A19	MR16 (120 V)	PAR20	PAR30	Combined	MR16 (12 V)	G25	B10
Retail Lamp Study 2 (2011)	Ratio of Means	\$0.37	\$0.46	\$0.46	\$0.68	\$0.49		\$0.53	
	Minimum	\$0.16	\$0.25	\$0.19	\$0.45	\$0.16	-	\$0.35	-
	Mean	\$0.37	\$0.47	\$0.47	\$0.70	\$0.51	-	\$0.54	-
	Maximum	\$0.80	\$0.57	\$0.65	\$1.26	\$1.26	-	\$0.78	-
Retail Lamp Study 1 (2010)	Ratio of Means	\$0.65	\$0.42	\$0.78	\$0.98	\$0.69	\$0.71		\$0.39
	Minimum	\$0.39	\$0.11	\$0.39	\$0.36	\$0.11	\$0.55	-	\$0.14
	Mean	\$0.68	\$0.51	\$0.79	\$1.03	\$0.74	\$0.77	-	\$0.52
	Maximum	\$1.19	\$1.09	\$1.03	\$1.67	\$1.67	\$1.16	-	\$0.88
Change	Ratio of Means	-43.5%	10.8%	-40.7%	-30.1%	-28.0%			
Change	Mean	-45.0%	-8.4%	-41.0%	-32.2%	-31.8%			



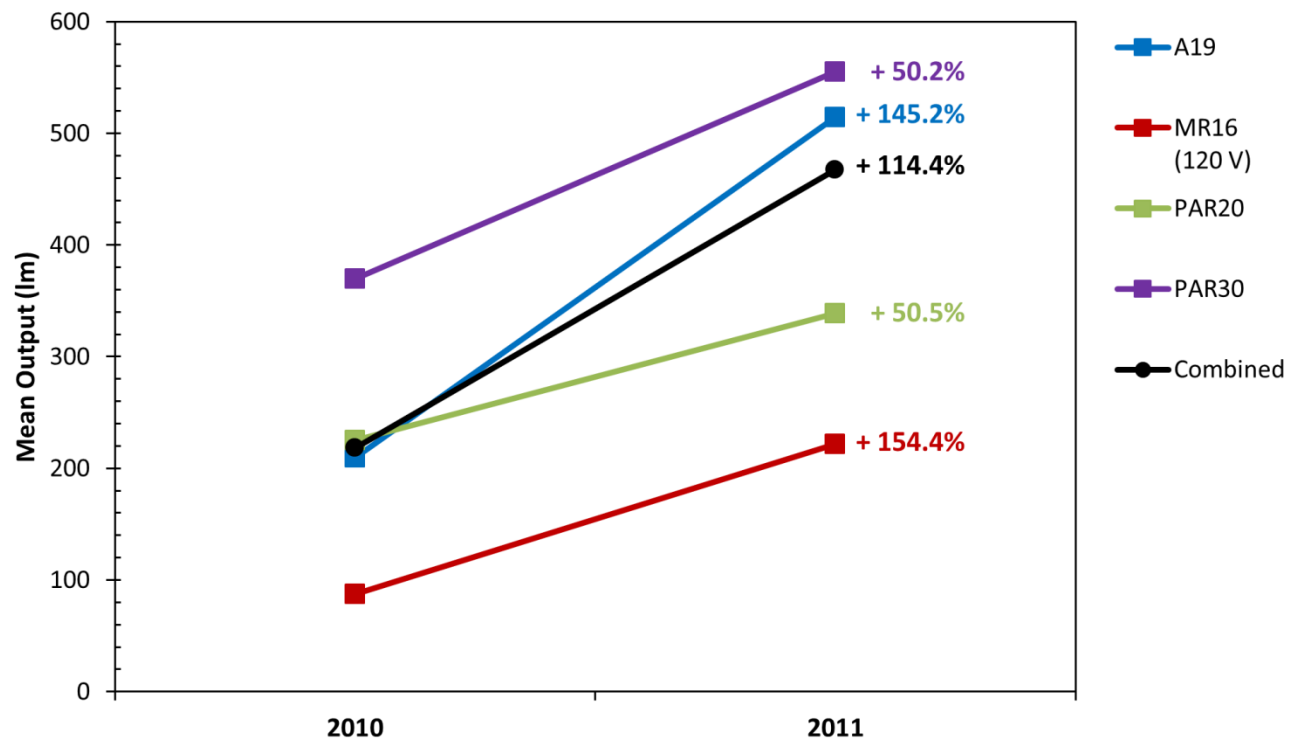
#### 4. Input Power (W)

		A19	MR16 (120 V)	PAR20	PAR30	Combined	MR16 (12 V)	G25	B10
Retail Lamp Study 2 (2011)	Minimum	1.6	0.8	2.1	8.0	0.8	-	2.3	-
	Mean	8.7	4.2	6.9	10.5	7.6	-	7.2	-
	Maximum	13.3	5.8	10.7	14.2	14.2	-	9.8	-
Retail Lamp Study 1 (2010)	Minimum	1.9	0.8	5.7	3.1	0.8	1.4	-	1.4
	Mean	4.8	2.2	6.2	8.1	5.1	4.1	-	1.7
	Maximum	8.1	4.1	6.5	11.6	11.6	7.3	-	1.8
Change	Mean	78.9%	92.0%	12.1%	29.5%	48.6%			



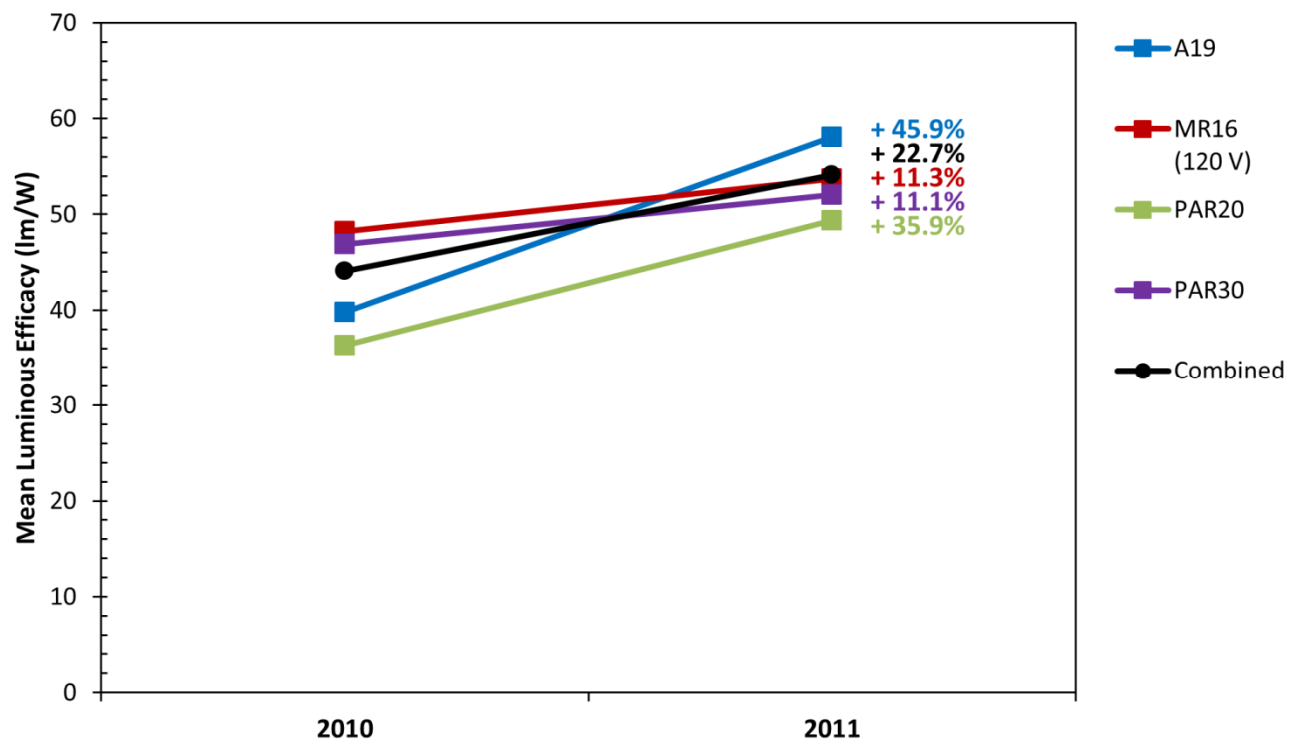
## 5. Output (lm)

		A19	MR16 (120 V)	PAR20	PAR30	Combined	MR16 (12 V)	G25	B10
Retail Lamp Study 2 (2011)	Minimum	84	48	110	346	81	-	81	-
	Mean	514	222	339	555	468	-	354	-
	Maximum	841	327	547	820	841	-	442	-
Retail Lamp Study 1 (2010)	Minimum	65	44	206	145	44	36	-	34
	Mean	210	87	225	369	218	138	-	65
	Maximum	412	149	255	559	559	191	-	106
Change	Mean	145.2%	154.4%	50.5%	50.2%	114.4%			



## 6. Luminous Efficacy (lm/W)

		A19	MR16 (120 V)	PAR20	PAR30	Combined	MR16 (12 V)	G25	B10
Retail Lamp Study 2 (2011)	Minimum	49	43	40	37	37	-	36	-
	Mean	58	54	49	52	54	-	47	-
	Maximum	71	61	55	72	72	-	56	-
Retail Lamp Study 1 (2010)	Minimum	34	23	32	35	23	25	-	18
	Mean	40	48	36	47	44	35	-	40
	Maximum	51	76	39	61	76	55	-	73
Change	Mean	45.9%	11.3%	35.9%	11.1%	22.7%			



**DOE SSL Commercially Available LED Product Evaluation and Reporting Program  
NO COMMERCIAL USE POLICY**

The U.S. Department of Energy (DOE) is a federal agency working in the public interest. Published information from the DOE SSL CALiPER program, including test reports, technical information, and summaries, is intended solely for the benefit of the public, in order to help buyers, specifiers of new SSL products, testing laboratories, energy experts, energy program managers, regulators, and others make informed choices and decisions about SSL products and related technologies.

Such information may not be used in advertising, to promote a company's product or service, or to characterize a competitor's product or service. This policy precludes any commercial use of any DOE SSL CALiPER Program published information in any form without DOE's express written permission.

